U.S. Coast Guard Research and Development Center
1082 Shennecossett Road, Groton, CT 06340-6048

Report No. CG-D-04-06

Extended Range Underwater Loudhailer for Port Security Applications

FINAL REPORT
June 2006

This document is available to the U.S. public through the
National Technical Information Service, Springfield, VA 22161

Prepared for:

U.S. Department of Homeland Security
United States Coast Guard
Assistant Commandant for Response (G-R)
Washington, DC 20593-0001

N O T I C E

This document is disseminated under the sponsorship of the Department of Homeland Security in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

This report does not constitute a standard, specification, or regulation.

Marc B. Mandler, Ph.D.
Technical Director
United States Coast Guard
Research & Development Center
1082 Shennecossett Road
Groton, CT 06340-6048

Technical Report Documentation Page

1. Report No. CG-D-04-06	2. Government Accession Number	3. Recipient's Catalog No.
4. Title and Subtitle Extended Range Underwater Loudhailer for Port Security Applications		5. Report Date June 2006 6. Performing Organization Code Project No. 5903
7. Author(s) Ric Walker[1] and Bruce Abraham[2]		8. Performing Report No. R&DC 704
9. Performing Organization Name and Address [1]U.S. Coast Guard Research and Development Center 1082 Shennecossett Road Groton, CT 06340-6048	[2]Applied Physical Sciences Corp. 2 State Street, Suite 300 New London, CT 06320	10. Work Unit No. (TRAIS) 11. Contract or Grant No. TSWG contract W91CRB-04-C-0057
12. Sponsoring Organization Name and Address U.S. Department of Homeland Security United States Coast Guard Commandant (G-R) Washington, DC 20593-0001		13. Type of Report & Period Covered Final 14. Sponsoring Agency Code Commandant (G-RPD, G-RPC) U.S. Coast Guard Headquarters Washington, DC 20593-0001

15. Supplementary Notes

The R&D Center's technical point of contact is Ric Walker, (860) 441-2728, Ric.T.Walker@uscg.mil.

16. Abstract (MAXIMUM 200 WORDS)

The U.S. Coast Guard (CG) has developed an Integrated Anti-swimmer System (IAS) to aid enforcement of security zones around high-value maritime assets. The IAS includes a diver recall system to issue verbal warnings and commands as the first response to a detected underwater intruder. However, the range of the recall system does not meet the CG's requirement of 500 yards for security zone enforcement. Consequently, this system must be deployed from a boat in close proximity to an intruder. This limitation consumes valuable time before a response is initiated, and might not be completely effective when multiple intruders are present.

This report describes the development and prototyping of a portable underwater loudhailer having an effective range goal of 500 yards. This loudhailer was designed and evaluated through a series of technical reviews, acoustic measurements, and field tests using divers in a realistic environment to measure the intelligibility of warning messages broadcast underwater. Design details, test procedures and test limitations are described, along with environmental and safety considerations. Test and evaluation results are presented, and are used as the basis for a set of recommendations toward maximizing operational performance of the underwater loudhailer.

17. Key Words port security, underwater, loudhailer, diver recall, Coast Guard, *e*LOUD		18. Distribution Statement This document is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161.	
19. Security Class (This Report) UNCLASSIFIED	20. Security Class (This Page) UNCLASSIFIED	21. No of Pages 157	22. Price

Form DOT F 1700.7 (8/72) Reproduction of form and completed page is authorized.

ACKNOWLEDGEMENTS

The work described in this report is the result of the coordinated efforts of many people from several government organizations and private industry.

The authors would like to express our appreciation to Mr. Jim Rice and the Technical Support Working Group for providing funding and contract support. The staff at the Naval Submarine Medical Research Laboratory provided critical expertise, test management, data collection, analysis, reporting, and dive team support. The efforts of Dr. Ed Cudahy, Dr. Michael Qin, and Ms. Alison America were invaluable. Critical assistance was also provided by the staff at the Naval Undersea Warfare Center in Newport, RI. In particular, Mr. Jim Pollock, Mr. Roy Manstan, Mr. Sam Carroll, and Mr. Jack Hughes offered outstanding support in providing a test site, political and logistical support, test execution, and reporting.

We appreciate the efforts of the divers of the Coast Guard Maritime Safety and Security Teams, the Naval Undersea Warfare Center, Division Newport's Engineering & Diving Support Unit, and the Naval Submarine Medical Research Laboratory (NSMRL) dive team. These divers served as test subjects in sometimes harsh conditions, and provided a critical service in evaluating the performance of the enhanced underwater loudhailer.

Lastly, the authors would like to acknowledge the unwavering support and dedication of Mr. Kenneth McDaniel at the Office of Security and Defense Operations, U.S. Coast Guard Headquarters.

EXECUTIVE SUMMARY

The U.S. Coast Guard (CG) has primary responsibility for providing security to high-value assets in our ports and waterways. In recent years, there has been a growing concern about the threat to port security from under the water's surface, primarily from combat swimmers and divers. The CG's Underwater Port Security (UPSec) mission requires the ability to detect, track, locate, identify, and interdict potentially hostile swimmers and divers. An Integrated Anti-swimmer System (IAS) has been developed that integrates these capabilities. The system is primarily used to aid enforcement of a typical 500-yard security zone established around a high-value maritime or shoreside asset designated for protection.

When an underwater threat is detected, the first response by port security forces is to issue verbal warnings and commands. The purpose of this response is to positively notify divers that they have entered a restricted area, and that they should surface immediately to avoid potential harm. The IAS currently uses a commercially-available diver recall device for this purpose. However, this device has a limitation for effective communication with divers of approximately 25–50 yards. This range does not meet the CG mission requirement for an underwater loudhailer with an effective range that can cover an entire security zone (500 yards). To make up for this shortfall, security teams must maneuver their boats within 25-50 yards of each suspected intruder, thereby adding an unacceptable delay to the onset of response actions.

The CG Research and Development Center, working in conjunction with the CG Office of Security and Defense Operations, and the Office of Counterterrorism and Special Missions Operations, developed a set of requirements for a new underwater loudhailer to fill this critical UPSec mission performance gap. A contract was awarded to Applied Physical Sciences of New London, CT, for the development of an enhanced underwater loudhailer to meet these requirements. Funding was provided by the Technical Support Working Group (TSWG).

This report documents the design, development, testing, and evaluation of the enhanced underwater loudhailer, known as *e*LOUD™. This new system was designed to project clear, intelligible warning tones and messages to divers to a range of at least 500 yards. The system is intended to be used by port security forces attempting to alert underwater swimmers that have entered a restricted area. The system can transmit a set of pre-recorded warning messages in a desired sequence, or it can send live voice messages by means of a handheld microphone. A Personal Digital Assistant (PDA) computer provides system control, message file management, and a user interface. Hundreds of messages in different languages can be loaded into the system's memory for playback. The loudhailer is portable, and can operate on internal battery power for more than two hours. Additional powering options are incorporated for extended use.

Field testing of *e*LOUD™ was conducted in a single saltwater location with relatively low background noise. Testing consisted of acoustic measurement (sound pressure levels (SPL) and waveforms) and intelligibility tests. Intelligibility tests used English warning phrases, and single words that were recorded using native English voices.

Performance testing and evaluation indicated that the *e*LOUD™ should meet all design and performance requirements; that is, the *e*LOUD™ should effectively notify underwater intruders

at a range of at least 500 yards. The loudhailer can therefore be deployed in a strategic location near a protected asset, or in close proximity to the diver detection system. If an underwater threat is detected, transmission of verbal warnings and commands can be initiated immediately, versus a response boat having to move to the location of the threat to deploy a system for notification.

Based on the performance of *e*LOUD™ during testing, we recommend that a number of prototype systems be distributed to operational units for evaluation. The test results were also used to develop recommendations for loudhailer operational procedures to maximize the system effectiveness and personnel safety during use. Recommendations for the format of warning messages are provided that should maximize the likelihood that an intruder will hear and understand the message. It is further recommended that high-quality recordings of the warning messages in languages other than English be developed for use with *e*LOUD™.

As a follow-on to the *e*LOUD™ development effort, TSWG funded the construction of 20 prototype loudhailers. In accordance with the recommendations of this effort, the prototypes have been distributed to units in the Coast Guard and Navy for operational use and evaluation. Evaluation comments from these units will be used to develop recommendations for improvements to the next version of *e*LOUD™. TSWG has contracted for the construction of up to 100 additional units of the next version for operational deployment by the Coast Guard, Navy and other port security forces.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

AC	Alternating current
Ah	Ampere-hour
APS	Applied Physical Sciences Corporation
CDR	Critical Design Review
CFR	Code of Federal Regulations
CG	U.S. Coast Guard
CONOPS	Concept of operations
COTS	Commercial off-the-shelf
dB	Decibel
DRS	Diver Recall System
EDSU	Engineering and Diving Support Unit
*e*LOUD™	Enhanced underwater loudhailer developed by Applied Physical Sciences Corporation under contract with TSWG.
FDR	Final Design Review
ft	Foot *or* feet
GPS	Global Positioning System
G-RPD	Office of Security and Defense Operations
GSA	General Services Administration
Hz	Hertz
HP	Hewlett Packard
IAS	Integrated Anti-swimmer System
kHz	Kilohertz
lb.	pound or pounds
LCD	Liquid Crystal Display
mA	Milliampere
MB	Megabyte
MHz	megahertz
mm	Millimeter
NEMA	National Electrical Manufacturers Association
NSMRL	Naval Submarine Medical Research Laboratory
NUWC	Naval Undersea Warfare Center
OTO	One-third-octave
PDA	Personal digital assistant
PDR	Preliminary Design Review
PTT	Push-to-Talk
RCA	Radio Corporation of America
RDC	Research and Development Center
RF	Radio frequency
RMS	Root mean square
SCUBA	Self-contained underwater breathing apparatus
SD	Secure Digital
SPL	Sound pressure level
SVP	Sound velocity profile

TSWG	Technical Support Working Group
UPSec	Underwater Port Security
U.S.	United States
USN	United States Navy
VAC	Volts of alternating current
VDC	Volts of direct current
vs.	versus
W	Watt

1. INTRODUCTION

The U.S. Coast Guard (CG), operating under the Department of Homeland Security, has the responsibility to provide security for our Nation's ports. In recent years, there has been increased concern regarding the potential threat from underwater sources. In recognition of this threat, the CG's Underwater Port Security (UPSec) mission requires the ability to detect, track, locate, identify, and interdict potentially hostile swimmers and divers.

As part of an effort to improve the CG's ability to provide underwater port security, an Integrated Anti-swimmer System (IAS) has been developed. The IAS is a mobile diver detection and response system designed to help enforce a security zone established around a high-value asset. The CG must enforce these security zones and prevent access by unauthorized individuals, both above and below the water. When an intruder is detected, one of the first responses is to issue verbal warnings and commands. The IAS currently includes a commercially-available diver recall system for this purpose. However the effective range of this system is only 25 to 50 yards, and it must be deployed by a harbor security response boat in the immediate vicinity of the diver in order to ensure effective communication. This range limitation increases the time to respond and does not satisfy the operational requirement that an underwater loudhailer be capable of covering an entire security zone. Security zones typically extend out 500 yards from a protected asset. A capability range of 500 yards is therefore a core operational requirement.

The CG Research and Development Center (RDC), working in conjunction with the Technical Support Working Group (TSWG), undertook the development of an enhanced underwater loudhailer to address this operational performance gap. As a result of a Broad Agency Announcement issued by TSWG, contract W91CRB-04-0057 was awarded to Applied Physical Sciences Corporation (APS) of New London, CT, in July 2004. TSWG funded the contract on the basis of CG requirements for an extended range underwater audio system for transmission of warning tones and messages to divers. The result was the Enhanced Underwater Loudhailer known as *e*LOUD™.

1.1 Purpose

The purpose of this report is to document the design, development, and performance testing of a prototype enhanced underwater loudhailer. It is intended to support CG program managers, and other port-security officials, who will be making decisions regarding the acquisition and operational deployment of this loudhailer. It is also intended to support the general information requirements of prospective users.

2. LOUDHAILER DEVELOPMENT

2.1 Requirements

The requirements for the enhanced underwater loudhailer were developed in conjunction with the CG's Office of Security and Defense Operations (G-RPD), acting as the primary sponsor. These requirements, as put forth in the contract solicitation, are as follows:

- It must transmit, or otherwise communicate, clear and proven intelligible commands automatically and continuously in English, to an underwater swimmer at a minimum distance of 500 yards from a protected asset, or from a security-zone patrol vessel, to a minimum water depth of 130 feet.
- It must have the capability to easily add languages other than English, and to be equipped with a microphone for use by security forces.
- It must be transportable by one person and easy to operate.
- The system control unit must be rugged for operation in harsh, saltwater and shock environments, waterproof to at least three feet underwater when closed; and be splash-proof when open and connected for operation.
- It must include a waterproof cable of at least 75 feet, for connecting the control box to the transducer.
- The transducer must be suitable for operating to depths of 30 feet.
- It must have an internal battery capable of powering the complete system for at least two hours, and of being charged by 115 volts of alternating current (VAC). In addition, it must be capable of operating directly from a vehicle or vessel on 12 volts of direct current (VDC). (The Contractor will determine the system hardware necessary to support continuous operations, including the length of time required to recharge each battery, and the number of batteries needed. Ideally, the system will both operate and recharge from either 12 VDC or 115 VAC power.)
- It must be deployable from shore (dock or pier), or from a small patrol boat. If the system is not omni-directional, a single operator must be able to aim the sound projector while deployed.
- It must be capable of generating and broadcasting a control tone and live voice commands, as well as storing and playing back up to five pre-recorded commands or announcements, up to one-minute long, in five different languages. The Contractor shall include the hardware and software necessary for the operator to insert, store, identify, sort, select, and play individual or groups of messages.
- It must be capable of attaching an above-water speaker for operator monitoring, and for broadcasting messages.

- It must not to be harmful to any living aquatic species. An environmental assessment must be performed prior to saltwater testing, addressing the proposed frequencies and sound-pressure levels, and any other environmental considerations.

2.2 Design

The enhanced underwater loudhailer (*e*LOUD™) was developed in response to the system requirements presented above. A rapid prototyping process was used in which several versions were built and evaluated prior to selection of a final prototype design (see Figure 1).

Figure 1. The design evolution of the enhanced underwater loudhailer.

For clarity, the following naming convention for the prototypes shown in Figure 1 was adopted:

Version 0.0	Initial prototype	March 2005
Version 1.0	Field test prototype	June 2005
Version 1.1	First article prototype	Sep 2005
Version 1.2	20-unit option prototypes	Jan-Feb 2006

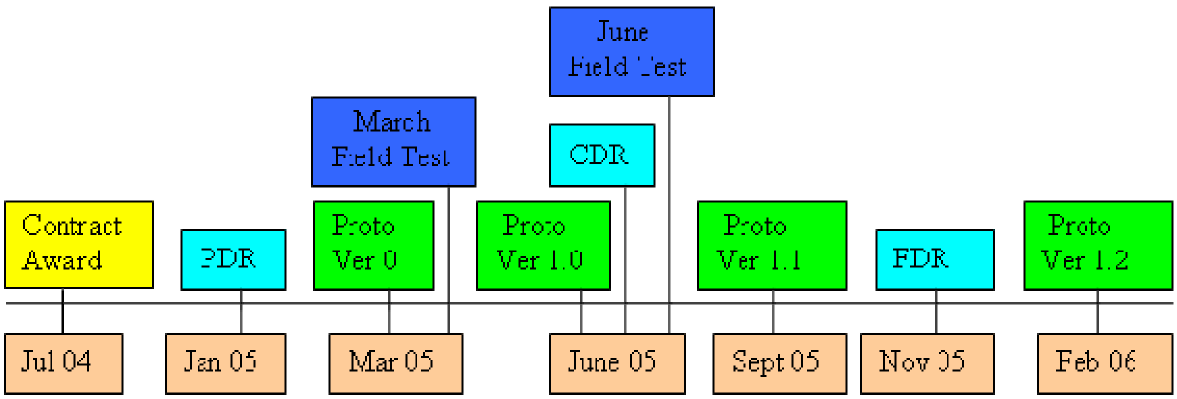
The core requirement for the enhanced underwater loudhailer was to generate and transmit audio signals of sufficient magnitude and spectral content for divers to be able to understand verbal warning messages at a range of 500 yards or greater. An acoustic requirements analysis (Abraham, 2004a) indicated that the underwater transducers should operate within 500 to 3000 Hz, and should compensate for the sound attenuation from a typical diver's neoprene hood at frequencies above 500 Hz. A source-sound pressure level (SPL) of approximately 190 dB[1] was calculated as the level necessary to overcome open-circuit regulator noise, background noise, and hood attenuation. This source level was based on the requirement for a minimum receive level, at the diver, of approximately 130–135 dB.

The loudhailer prototype was designed to generate this SPL at the 2700-Hz transducer resonance frequency at a range of 500 yards to meet the operational performance requirement. The acoustic performance of the proposed design concept was validated early in the development phase by testing performed at the Naval Undersea Warfare Center's calibrated acoustic test facility at Dodge Pond in Niantic, CT (Abraham, 2005).

An important functional feature of the *e*LOUD™ is the ability to store, record, and transmit multiple messages in different languages. A low-cost Personal Digital Assistant (PDA)

[1] All sound pressure levels are referenced to one micropascal at one meter (re 1µP @ 1m).

computer was selected to perform these functions, and to serve as the primary user interface. Custom software was developed to run on a Hewlett Packard (HP) iPAQ PDA. Several design reviews were conducted during development to ensure that the product would meet the mission and end-user requirements. The design choices were guided by government feedback at the design reviews, by APS internal testing, and by two field test events managed by the government. Figure 2 illustrates the iterative process of this development.



Jul 04	**Contract Award**
Jan 05	**Preliminary Design Review (PDR)**
Mar 05	**Loudhailer Prototype Version 0.0**
Mar 05	**March Field Test**
Jun 05	**Loudhailer Prototype Version 1.0**
Jun 05	**Critical Design Review (CDR)**
Jun 05	**June Field Test**
Sep 05	**Loudhailer Prototype Version 1.1 delivered**
Nov 05	**Final Design Review (FDR)**
Feb 06	**Loudhailer Prototype Version 1.2 – 20 units delivered**

Figure 2. Sequence of events during loudhailer prototype development.

2.3 Field Testing

Version 0.0 was tested in March 2005 at NUWC in Newport, RI, to measure the sound power output in a shallow, saltwater environment. SPL measurements were made as a function of frequency, range, source depth, and receive depth. An informal assessment of the system intelligibility was also conducted, using a limited number of divers listening to tones and warning phrases at ranges out to 600 yards. The March Field Test is described in more detail later in this report and in APPENDIX A and APPENDIX B.

A second and more formal field test was performed at NUWC in June 2005. The purpose of the June Field Test was to evaluate the Version 1.0 design and to obtain quantitative diver intelligibility performance results. Staff from the Naval Submarine Medical Research Laboratory (NSMRL), with expertise in acoustics, audiology and diving operations, designed

and managed the test, which was conducted with the assistance of RDC and NUWC's Engineering and Diving Support Unit (EDSU). The June Field Test is described in more detail later in this report and in APPENDIX C and APPENDIX D.

Testing validated the field test prototype design and performance. Several minor modifications were suggested on the basis of test results and user feedback. These changes were incorporated into Version 1.1, which was the product delivered by APS to satisfy the requirements of the base contract. TSWG subsequently exercised a contract option with APS to build 20 prototype units for operational use and evaluation. Several additional improvements and design changes were incorporated into Version 1.2, delivered under this contract option. A summary of the significant features and changes to each prototype version loudhailer follows:

<u>Version 0.0 (Initial Prototype Unit)</u>:

- Fully-functional Loudhailer
- Class AB, 300-watt amplifier (22 percent efficiency)
- Sealed lead acid 12 ampere-hour (Ah) battery
- 800-milliampere (mA) battery charger
- Rev 0 of PDA control software
- HP iPAQ 2215 PDA beneath flexible, splash-proof screen (PDA microphone hard-wired)
- Messages installed on removable 256 megabyte (MB) Secure Digital Card
- Condenser microphone (requires separate power)
- Large National Electrical Manufacturers Association's (NEMA) enclosure, large Pelican™[2] case
- Three-element transducer array

<u>Version 1.0 (Field Test Unit)</u>:

- Class AB, 200-watt amplifier (22 percent efficiency)
- Step-up transformer changed to provide higher transducer voltages (at cost of some distortion)
- Rev 1 of PDA control software (improve button usability)
- HP iPAQ 2215 PDA beneath flexible, splash-proof screen (microphone input hard-wired)
- Moving-coil microphone (does not requires separate power)
- Marine-style rocker power switches
- Control Unit integrated into Hardigg Stormcase, which is splash proof when open; waterproof when closed
- Transducers stored in separate Hardigg Stormcase

<u>Version 1.1 (First Article Prototype Build)</u>:

- Class D, 400-watt amplifier (88 percent efficiency), 20 kilohertz (kHz) bandwidth
- Change transformer to reduce distortion while still increasing overall sound power
- Rev 2 of PDA control software (including recorded message filtering and normalization)

[2] Pelican™ Products is a manufacturer of watertight protective cases for waterproof storage.

- HP iPAQ 2215 no longer available; switched to HP iPAQ 2400 PDA (microphone input hard-wired)
- Engraved front panel
- Caps for power, microphone, and transducer connectors tethered to front panel
- Power switches changed to toggle switches

Version 1.2 (20-Unit Option Prototype):

- Class D switching frequency lowered to reduce bandwidth and to provide better trigger/fault performance
- 1500-mA battery charger (decreases charging time)
- PDA operating system upgraded to Windows® Mobile™ 5.0, which has non-volatile memory when used with HP iPAQ 2400 (no data loss after complete power failure)
- Simplified PDA mounting bracket for front panel
- Caps for power, microphone, and transducer connectors tethered to front panel
- Lockout cover added to main power switch to prevent accidental turn-on
- User manual mounted inside cover of control unit
- Spare parts, power cables, charger, and speaker stored in transducer case
- Transducer suspension harnesses eliminated; replaced with mounting pegs on each transducer

3. VERSION 1.1 SYSTEM DESCRIPTION

The underwater loudhailer prototype Version 1.1 incorporated feedback from the CDR and the lessons leaned from the June Field Test. The primary power components were a high-efficiency commercial off-the-shelf (COTS) Class[3] D, 400-watt root-mean-square (RMS) audio amplifier supplied by a 12-Ah sealed lead acid battery. The battery was directly connected to the amplifier (with its own fuse), and the amplifier was enabled by means of a separate trigger connected to a 'Transmit Enable' switch on the front panel.

The transformer was changed to match the new amplifier to reduce distortion of the output signal, and to increase overall sound power. The unit had flexible powering options, including the internal battery, external 12 VDC, and standard 115 VAC. A 1500-mA battery charger was incorporated to reduce charging time.

The control computer was an HP iPAQ PDA mounted beneath a splash-proof screen. The PDA ran a revised version of the custom software that enabled warning message selection, playback, and recording. In addition, the new software allowed a recorded message to be normalized and filtered in a manner similar to the pre-recorded messages for improved performance underwater. Several modifications to the PDA, and to related circuitry, were necessary to enable use of an external microphone for live voice broadcast.

All the control electronics were integrated into a molded plastic resin case having an overall weight of 35 pounds. The case was waterproof to three feet when closed and splash proof when open.

Figure 3 shows the Version 1.1 prototype control unit. A waterproof battery-voltage meter was added. The main power switch and the transmit enable switch were changed to waterproof toggle switches. An RCA audio jack[4] was added to allow connection of an external speaker for monitoring system output. Bulkhead connectors for the transducer, microphone, and external power were mounted on the control panel, and tethered caps were added. The new front panel used engraved lettering for all labels.

[3] Amplifier circuits are classified as A, B, AB, and C for analog designs; class D and E for switching designs. For the analog classes, each class defines what proportion of the input signal cycle (called the angle of flow) is used to actually switch on the amplifying device. In a class D amplifier, the output transistors are operated as switches, and the power dissipation is very low. This increases efficiency, thus requiring less power from the power supply, and smaller heat sinks for the amplifier. These are important advantages in portable, battery-powered equipment.

[4] An RCA audio jack is an analog electrical connector commonly used in the audio market. The name 'RCA' derives from the Radio Corporation of America, which introduced the design, by the early 1940s, to allow phonograph players to be connected to radios.

Figure 3. Control unit for the loudhailer prototype version 1.1.

One of the key features of the loudhailer design is the use of a linear 3-transducer array. This approach improved the vertical directivity of the outgoing signal, thereby reducing reverberation in shallow water, and improving message clarity and range. The transducer array consists of three lightweight Ocean Engineering Enterprises DRS-8 transducers, configured in a vertical line array. The resulting beam pattern is omni-directional in the horizontal plane and 20 degrees in the vertical plane, at a frequency of 2 kHz. The center-to-center spacing of the transducers is 24 inches, and the overall array height is 56 inches. Non-rigid connections were used to allow compact storage. Use of a small ballast weight (10–15 lbs) on the bottom of the line kept the array within 15 degrees of vertical. The transducers are stored in a waterproof plastic resin case, as shown in Figure 4. This case is slightly larger than the control case, and has a total weight of approximately 28 pounds. For ease of handling, the ballast weight is not included in the system.

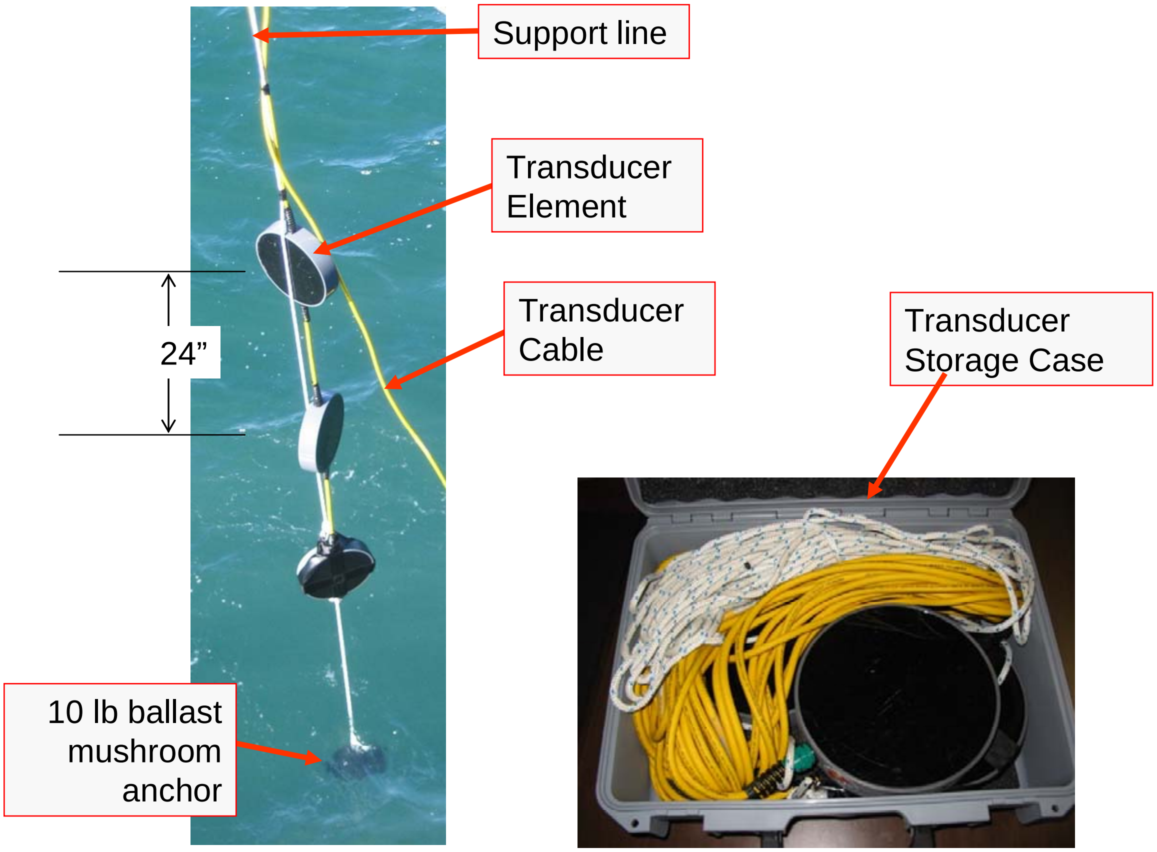


Figure 4. *e*LOUD™ transducer array and storage case.

3.1 Version 1.1 Control Software Description

The primary controller for the underwater loudhailer is an HP iPAQ 2400 PDA computer, which has a 400-megahertz (MHz) processor, and a color touch display. The PDA is mounted to the underside of the loudhailer control panel, and is covered by a flexible touch screen that allows splash-proof operation. The PDA enables selection, playback, and recording of warning messages and tones. The audio output has two channels: one channel connected to the power amplifier by way of a relay; the other channel connected to a jack with an external amplified speaker. This arrangement allows the operator to monitor the PDA audio output.

The control software runs from an external Secure Digital (SD) card, and uses the file management and audio input and output capabilities of the PDA. Software rather than hardware updates can be used for functionality upgrades. In Version 1.2, the *e*LOUD™ software application remains the same, but the PDA operating system was upgraded to Microsoft® Windows Mobile™ 5.0, to allow for complete battery failure without loss of program data.

The control program on the PDA has three main screens: Playback, Setup, and Record (see Figure 5). The Playback (main) screen allows users to transmit messages defined on the Setup screen. The Setup screen allows users to select messages for playback, by defining a playlist. The message format is Microsoft Wave, mono, 11025-Hz sample rate, 16 bit. The Setup screen also allows users to define how many times a message will be repeated, and whether or not the entire playlist should be repeated. In addition, it allows users to increase the volume from 33 percent to 66 percent, to 100 percent, for each successive playing of a playlist. This feature could be useful for safe operations with friendly divers at relatively close ranges (25–150 yards).

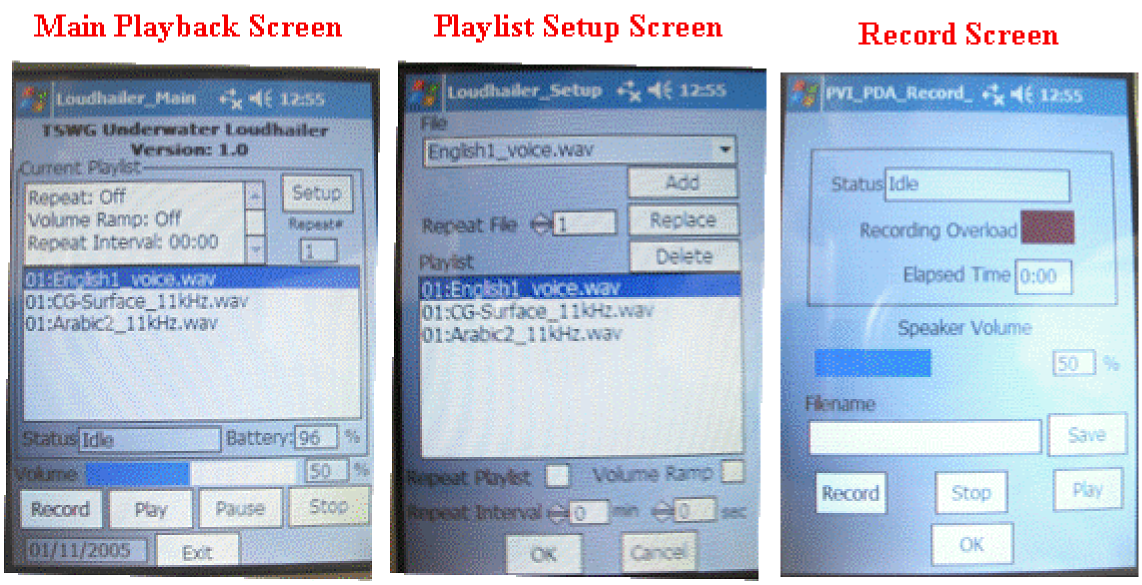


Figure 5. Control screens on the *e*LOUD™ PDA.

The Record screen allows users to record messages, check them, and save them to files. These files are then available for playback. The control software can perform filtering operations on recorded messages to optimize them for playback to underwater listeners.

3.2 Final Prototype Design

The spiral design process used in the development of the *e*LOUD™ resulted in four distinct prototypes, as shown in Figure 1. For the purposes of the base contact, Version 1.1 was delivered as the *e*LOUD™ prototype. However, continuing development efforts by APS provided additional input for design enhancements, as described in Section 2.3. In addition, improvements to some of the COTS components, particularly the PDA software, were released during the *e*LOUD™ development process. When TSWG awarded a contract option to APS to build 20 prototype units, these enhancements were incorporated into the Version 1.2 prototype, as the latest design in the spiral process (see Figure 6). Version 1.2 prototype was evaluated and approved by the government in the Final Design Review. The recommended specifications for the final prototype are the Version 1.2 specifications, and are presented in APPENDIX E, along with a set of drawings and photos.

Figure 6. Control unit for the loudhailer Version 1.2.

4. *e*LOUD™ TEST AND EVALUATION

This section provides a summary of the underwater testing and evaluation that was conducted in support of the development and final design of the loudhailer. Early in the project, several electro-acoustic tests were performed at NUWC's Dodge Pond Acoustic Test Facility to support the selection of various components, such as the power amplifiers and transducers, and to verify their performance (Abraham, 2004b, Abraham, 2005). Testing of the complete system was conducted during March 2005 (Version 0.0) and June 2005 (Version 1.0), and is summarized below.

The following background and assumptions were used in the development and testing of the underwater loudhailer:

The system will generally be used in conjunction with an underwater threat detection system, such as the IAS. Once a threat has been detected (by IAS or other means), the underwater loudhailer will be turned on and will transmit warnings and commands to the intruder. The operating environment will be in a commercial port or waterway with water depths typically in the 30–60 foot (ft) range. While an intruder might enter at any depth possible, the most probable depth is assumed to be 20 ft.

The message format has the following characteristics to maximize intelligibility:

- A hi/lo warning tone starts the message, to get the diver's attention. A diver will typically stop breathing momentarily to minimize the noise of exhalation bubbles and listen. The hi/lo tones sound much like a siren on an emergency vehicle. The specific hi and lo frequencies were selected to match the transducer peak-response characteristics, around 550 Hz (lo) and 2700 Hz (hi), for maximum efficiency and sound projection.
- The voice messages are short and concise. The messages proceed in a logical fashion as the situation unfolds (i.e., "This is your first warning…"; "This is your second warning…").
- The tones and voice messages are each repeated once.

4.1 March 2005 Field Test

Testing of the Version 0.0 prototype was conducted in March 2005 at NUWC's Stillwater Basin in Newport, RI. This testing was designed to measure quantitatively the sound power output of the prototype underwater loudhailer in a real-world, shallow-water environment. The Stillwater Basin was chosen for this reason, as it has a depth of 35–50 ft, which is typical of many commercial harbors. This same site has been used previously for testing both diver-warning systems (Rehn et al, 2004) and diver-detection systems, including the CG's IAS. During the testing of the Version 0.0 prototype, the propagation conditions were favorable in that there was minimal vessel traffic, minimal background noise, and the temperature profile was nearly isothermal, the latter condition ensuring against upward and downward-refracting sound. Collectively, these conditions minimized acoustic transmission loss, and maximized the range of direct-path transmissions.

The loudhailer was set up on the west end of NUWC's Pier 1, in the Stillwater Basin (Figure 7). The transducer array was suspended from an 8-ft long cantilever beam to displace it from the pier pilings. The water depth off the pier was 35 ft, so the test depths of the source (center) transducer of 9 ft, 18 ft, and 27 ft, were chosen to represent shallow, mid-water, and deep deployments, respectively. The loudhailer control unit was set up on the pier deck, and was connected to the transducer array. The PDA was used to transmit all test tones, chirps, and all other audio signals except live-microphone transmissions.

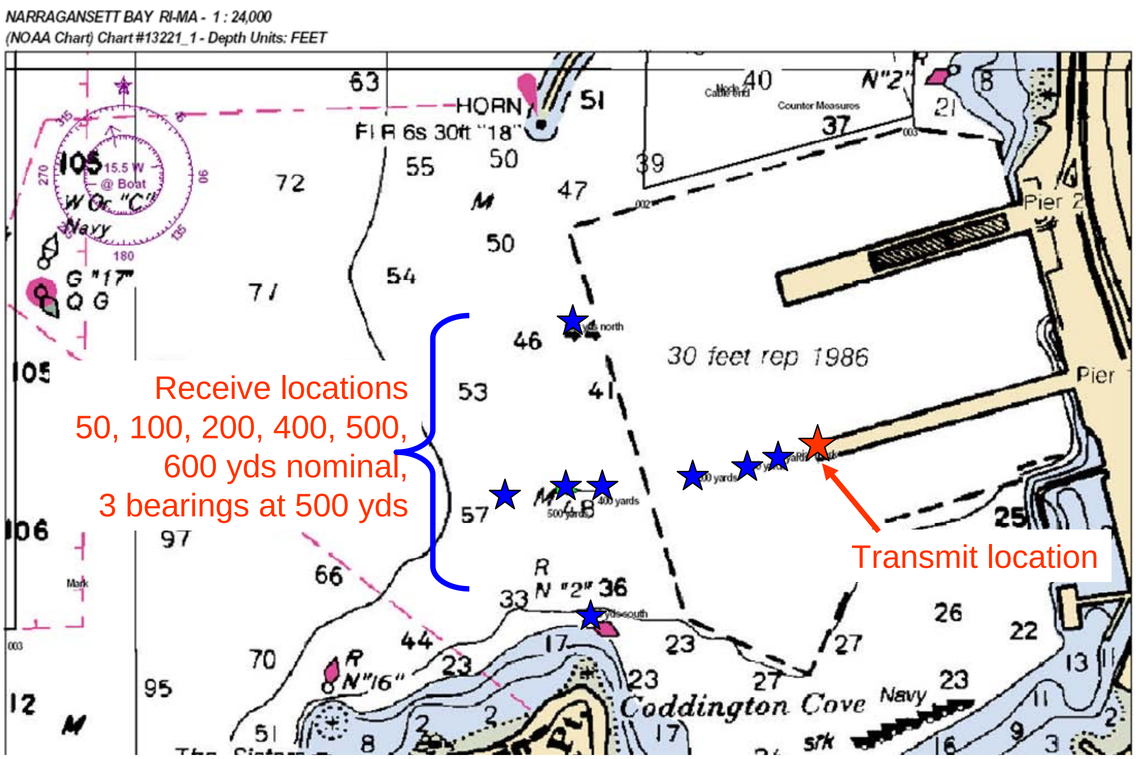


Figure 7. NUWC Stillwater Basin test area.

The receive hydrophone was deployed from a workboat, and was lowered to one of four test depths (7.5, 15, 30, 35 ft). A laser rangefinder, and a shipboard Global Positioning System (GPS), were used to position the boat at test distances ranging from 50 yards to 500 yards. The receive locations were generally on a line extending due west from the end of Pier 1; however, tests were conducted at three different bearings at the 500-yard range, as shown in Figure 7. The combination of different source depths, receiver depths, and receiver bearings was used to assess the sensitivity of transducer and listener location and depth on overall sound level. Custom analysis programs were used to calculate the spectrogram (frequency vs. time), and the maximum narrowband and one-third-octave SPLs (frequency vs. intensity). In addition, an informal assessment of the system's intelligibility was conducted using a limited number of divers listening to tones and typical warning phrases at ranges of 100, 200, 400, and 600 yards.

4.2 March 2005 Test Results

Results from the initial prototype test indicated that, in general, the range was the dominant factor affecting the sound pressure level, at the various test locations. Transmission loss was characterized as falling between cylindrical and spherical spreading. The prototype loudhailer was able to achieve a maximum SPL of 138-145 dB, at a range of 500 yards (see Figure 8), which exceeds the calculated minimum-required SPL of 135 dB for adequate sound reception at the diver. In addition to using multiple ranges, and source and receiver depths, tests were conducted using different receive locations (bearings). These locations were further south (toward a shoal), and further north (toward a breakwater), relative to the previous test locations. The range was 500 yards. The spatial variations in the received pressure field, due to different source depths, receiver depths, and receiver bearings, were generally less than +/- 5 dB. These acoustic performance measurements served as an initial validation of the loudhailer prototype design, including the source transducer array, audio amplifier, control PDA, and software.

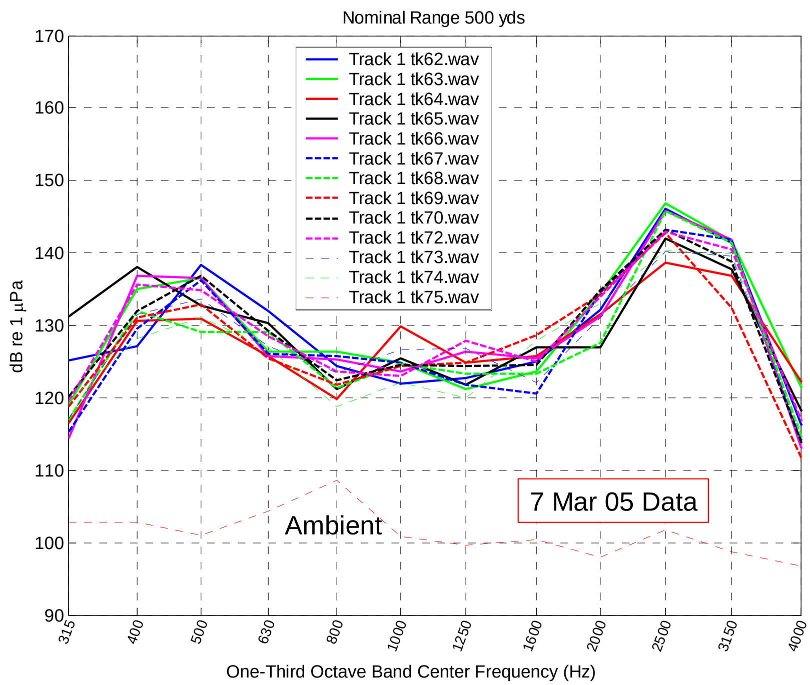


Figure 8. Maximum receive SPL at 500-yard range.

During the second phase of testing, divers were positioned at test ranges spanning from 100 to 600 yards. They listened to several warning tones and port security messages, and were asked to write down what they heard. A typical transmission included a hi/lo siren tone, a verbal warning message, and another hi/lo siren, and then the verbal message was repeated. Out of 28 transmissions, 27 were heard correctly (96 percent informal intelligibility). The one exception occurred when the beginning of a phrase was not preceded by a siren tone, and the diver was breathing during the first and second transmissions. This highlights the significance of breathing during any underwater voice transmission; the negative impact on intelligibility.

The overall results of the March test were excellent. Acoustic measurements indicated that the SPL at all ranges out to 500 yards exceeded the minimum level necessary for sound reception by a diver, even in the presence of regulator noise. This result was supported by subsequent tests in which divers detected the presence or absence of a warning tone at all depths and all ranges out to 600 yards. The divers also correctly heard the transmitted warning messages, with one exception, as noted above.

Qualitative responses from the divers indicated a telephone-like quality to the transmissions. They clearly heard both the male and female voices. Anecdotal reports from the divers indicated that they understood the female broadcasts better than the male, but the data does not support this. Test results showed that the loudhailer output was essentially omni-directional in the horizontal direction. Testing at depths down to 30 feet also showed the loudhailer performance to be essentially independent of the depth of the source or the receiver over this range. Ambient noise from local shipping traffic was quite low, due to the time of year, and this, in conjunction with the favorable acoustic conditions, might have contributed to some of the success, particularly at the longer ranges.

For a more complete description of the Version 0.0 prototype field test conducted in March 2005, refer to the APS Test Report in APPENDIX A, and the NUWC Test Report in APPENDIX B.

4.3 June 2005 Field Test

Based on the March field test results and APS's ongoing prototype development efforts, several changes were incorporated into the design that resulted in the Version 1.0 prototype. In particular, the 300-watt class AB amplifier used in Version 0.0 was replaced by a 200-watt class AB amplifier. This change was based on a power-requirements analysis indicating that 200 watts could meet the minimum power required, and on the fact that the larger amplifier could not meet the requirement to operate on battery power for two hours.

Version 1.0 field testing was conducted in June 2005 to quantitatively measure both diver intelligibility and sound pressure levels of loudhailer broadcasts. The testing was conducted at the NUWC Stillwater Basin. Technical and logistical support was provided by the NUWC EDSU. NSMRL staff designed and managed the execution of the diver intelligibility tests; APS performed the sound pressure level measurements.

The configuration for testing Version 1.0 was the same as used during the previous prototype tests. The loudhailer was set up on the west end of NUWC's Pier 1 in the Stillwater Basin. The transducer array was deployed from a cantilevered beam off the pier, in 35 feet of water. Because the depth of the transducer array had little effect on the measured SPLs in March, the center of the transducer array was kept at a depth of 15 feet throughout this test. An Ocean Technology DRS-100B Diver Recall System was also used during the test. This device is currently used with the Coast Guard's IAS for underwater hailing, and was included for comparative purposes. The DRS's single transducer was deployed to a depth of 9-ft depth (limited by the cable length, not by a system-depth limitation). The DRS-100B was driven by the same audio signal as was used for the *e*LOUD™ prototype. These tests were performed both for quantitative comparisons of system loudness and for qualitative listening.

For intelligibility testing, the prototype loudhailer was used to broadcast two basic kinds of stimuli: (1) standard monosyllabic word lists, and (2) port security phrases typical of those used by the Coast Guard. NSMRL selected the Auditec (www.auditec.com) Northwestern University Standardized Test Number 6 (NU-6) word list recordings for the test. NU-6 is a standard word recognition test used in audiologic assessments. For these tests, standard in-air testing procedures were adapted for use by divers in the water. The audio recordings were parsed into 200 individual audio files, and then grouped into sets of 25 words, in random order, for playback. Initial field results were poor, due to the low tenor of the speaker (i.e., muffled, low-fidelity sound). The recordings were then filtered and normalized, resulting in significantly better results during subsequent testing. An example recording consisted of the speaker saying, “Say the word…cat.” Divers receiving the stimulus would then write down the word as they heard it. An example word list used during the testing is shown in Table 1.

Table 1. Example NU-6 Word List used for loudhailer field test.

Word #	Test Word	Word #	Test Word
1	Chalk	14	Jail
2	Limb	15	Third
3	Burn	16	Puff
4	Tip	17	Dime
5	Fat	18	Goose
6	Which	19	Nag
7	Size	20	Gap
8	Sure	21	Knock
9	Love	22	Boat
10	Raise	23	Choice
11	Pool	24	Vine
12	King	25	Tough
13	Hurl		

In addition, 20 different warning phrases were used as stimuli during the intelligibility testing. These were very similar to the phrases used for the initial prototype test. Each list consisted of five phrases preceded by a short hi/lo siren. Although the siren is not part of the standard in-air intelligibility test procedure, it is part of the intended underwater loudhailer message format and deployment protocol, and therefore was included in the test messages. An example phrase list is shown in Table 2.

Table 2. Sample diver warning phrase list used for loudhailer field test.

Phrase #	Phrase	Speaker Gender
1	This is your final warning.	Male
2	Last warning. Surface immediately.	Male
3	Take off your mask.	Male
4	This is your first warning.	Male
5	Stop. You will be harmed.	Female

The divers were taken to the test range by a dive boat. When in position, the dive boat anchored and shut off its engines. All divers wore a standard 7-mm neoprene wetsuit with hood, and open-circuit breathing apparatus. Diver pairs were deployed, and descended to the desired depth

with a dive slate and grease pencil. During testing, the divers were oriented vertically on a weighted descent line off the side of the dive boat. For each test, the divers were instructed to record what they heard on the slate. The ranges for the single-word-identification tests were 50 yards and 100 yards, with test depths of 5 ft, 15 ft, and 30 ft. The ranges for the warning-phrase test were 50 yards, 100 yards, and 400 yards. The same diver depths of 5, 15 and 30 ft were used at each range.

4.4 June 2005 Test Results

4.4.1 Acoustic Measurements

The pressure level received from the *e*LOUD™ system was measured at 50, 100, 200, 400, 500, and 1000 yards, with receive depths of 5, 15, and 30 ft. The range effects were qualitatively very similar to those from the initial prototype test, in that there were variations on the order of +/- 5 dB in the levels. However, the overall levels were lower, especially at the longer ranges (see Figure 9). This difference is primarily attributed to increased transmission losses in June. Based on the *e*LOUD™ receive levels for the 2.5-kHz band, the transmission loss was roughly spherical (TL = 20 log R, where TL is the Transmission Loss in dB, and R is the Range in meters) from 100 to 200 yards, and more severe (TL ~27 log R) from 100 to 400 yards.

These propagation conditions were much different from the transmission loss observed (TL ~ 18 log R) in the same location during the March 2005 tests. For example, at 504 yards, the SPL was 136 dB in June versus 142 dB in March. At closer ranges, the differences are smaller (1.7 dB), and can be explained by the smaller (200-watt) amplifier in the Version 1.0 prototype unit tested in June, versus the 300-watt amplifier in the Version 0.0 prototype tested in March.

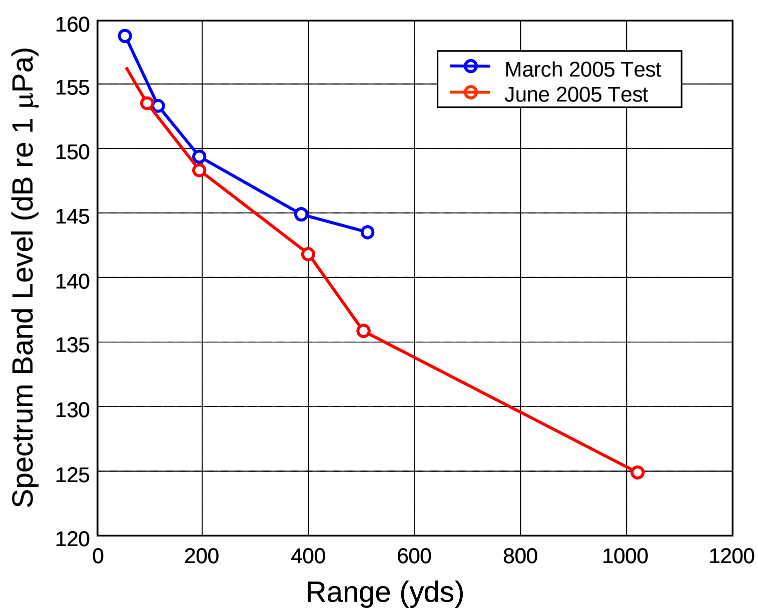


Figure 9. Maximum levels from March and June loudhailer tests for 2500-Hz band (which includes 2700-Hz sensor resonance). Data are averaged across source/receiver depth combinations.

In general, the received levels measured at the test depths were reasonably consistent, so the mean received levels were averaged across depth, and plotted as a function of frequency and range (see Figure 10). The figure illustrates a consistent attenuation across the spectrum of frequencies as a function of range (i.e., range has little effect on the overall spectral shape or relative frequency content). Thus, the received-level spectrum at 500 yards is similar to the received-level spectrum at 400 yards. This means that while the volume of a voice transmission will decrease with range, the overall sound quality remains undistorted. It is also important to note that the received levels are generally well above the threshold of hearing for a hooded diver at ranges out to 500 yards. These facts are important, and support the extrapolation of diver speech-reception performance at 500 yards in the conclusions of this report.

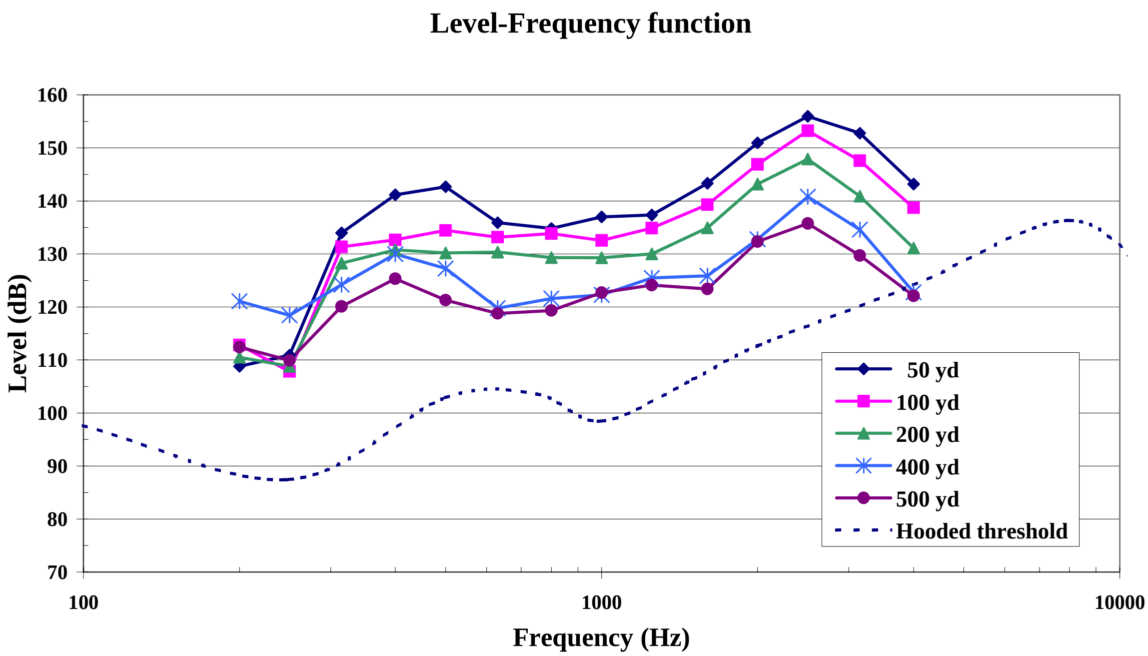


Figure 10. Received sound pressure levels as a function of frequency and receiver range averaged across depth. Average threshold of hearing of a hooded diver is included for reference.

Figure 11 shows a comparison of the maximum received-pressure spectrum for the *e*LOUD™ field-test unit and the DRS-100B, compared to the background ambient-noise level. The frequency bandwidth of the particular transducers used by the two systems is evident in the spectral response, as detailed in the Transducer Final Design Report (Abraham, 2005). The DRS-100B uses a Lubell Labs transducer, which has a first resonance at 1 kHz. The Ocean Engineering DRS-8 transducers used by the *e*LOUD™ system have resonances at 500 and 2700 Hz. The 20-dB higher SPL at 400 Hz and the 12-dB higher SPL at 2700 Hz generated by the *e*LOUD™ system, outweigh the 12-dB advantage the DRS has at 1250 Hz, as evidenced by the longer effective ranges for *e*LOUD™.

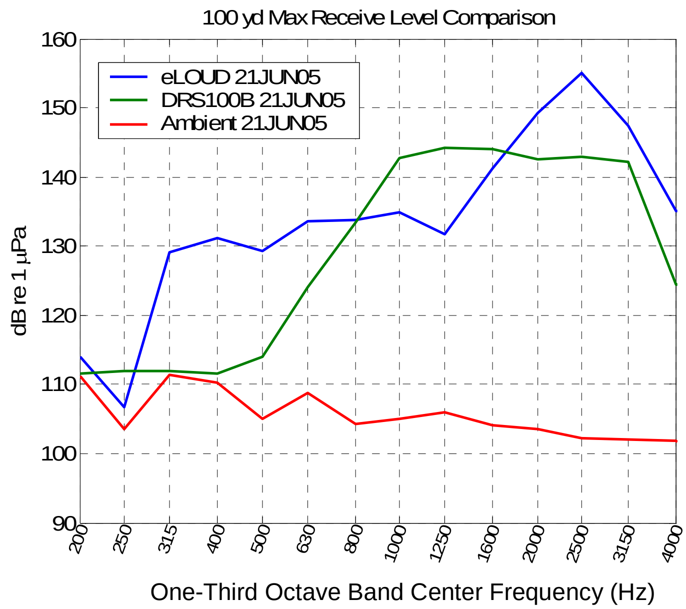


Figure 11. Comparison of *e*LOUD™ and DRS-100B receive pressure spectra at 100-yd range; *e*LOUD™ source depth = 15 ft, DRS-100B source depth = 9 ft, and both receiver depths = 15 ft.

Similar comparisons of the *e*LOUD™ and DRS-100B systems at ranges of 200 and 400 yards are presented in APPENDIX C.

4.4.2 Intelligibility Test Results

The intelligibility of single words by divers was tested at 50 and 100 yards, at depths of 5, 15, and 30 feet. The percent of single words correctly understood by divers ranged from approximately 90 percent at 50 yard to 70 percent at 100 yards. Intelligibility generally decreased with range, which was consistent with the lower pressure level measured acoustically. Intelligibility of single words also generally decreased with depth, which was not consistent with expectations based on the measured receive levels, which varied little with depth (see Figure 12).

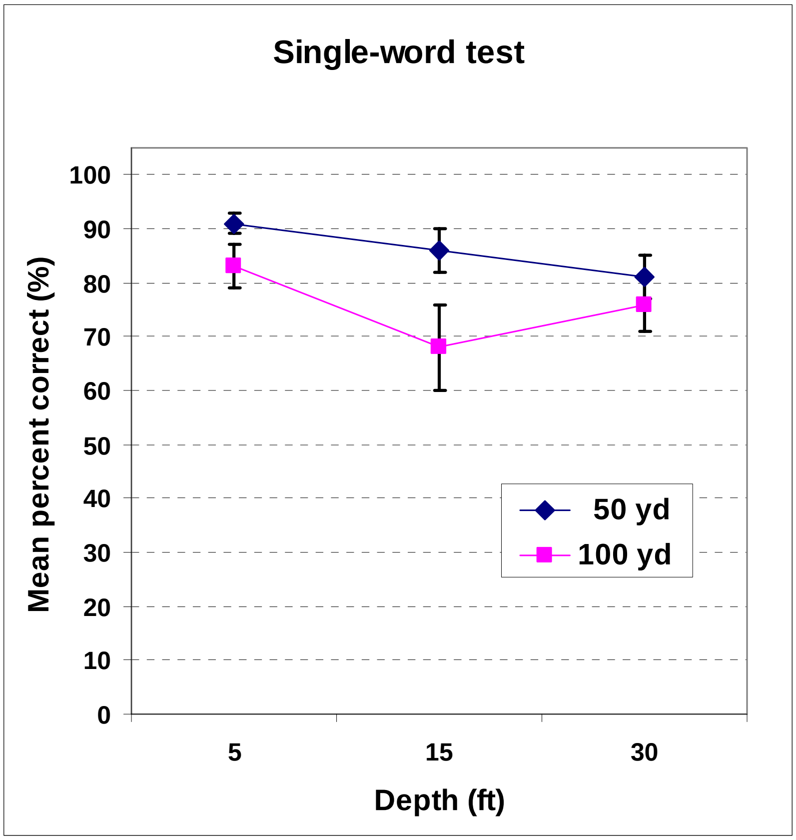


Figure 12. Mean percent correct of single-word identification as a function of diver depth, with the range of the diver from the source as a parameter.

The results of intelligibility testing at ranges from 50 to 400 yards, using warning phrases, were much better. In all cases, divers correctly understood the phrases over 90 percent of the time. Statistical analysis indicated no effect of range or depth on intelligibility over the test regime. Acoustic measurements supported this result in the case of depth effects, but it was unexpected with regard to range.

It was assumed that the levels of warning-phrase-identification performance were so high (>90 percent) that they produced a "ceiling effect." In essence, this effect refers to the fact that the system capabilities exceeded the requirements for effective phrase recognition under the conditions and ranges tested; a ceiling of 100 percent could not be exceeded. Because intelligibility testing at ranges longer than 400 yards was not possible, due to operational area restrictions and diver-safety issues, the system capabilities were not fully challenged for phrase recognition over the test regime; this situation led to the lack of significant effects of both range and depth (see Figure 13).

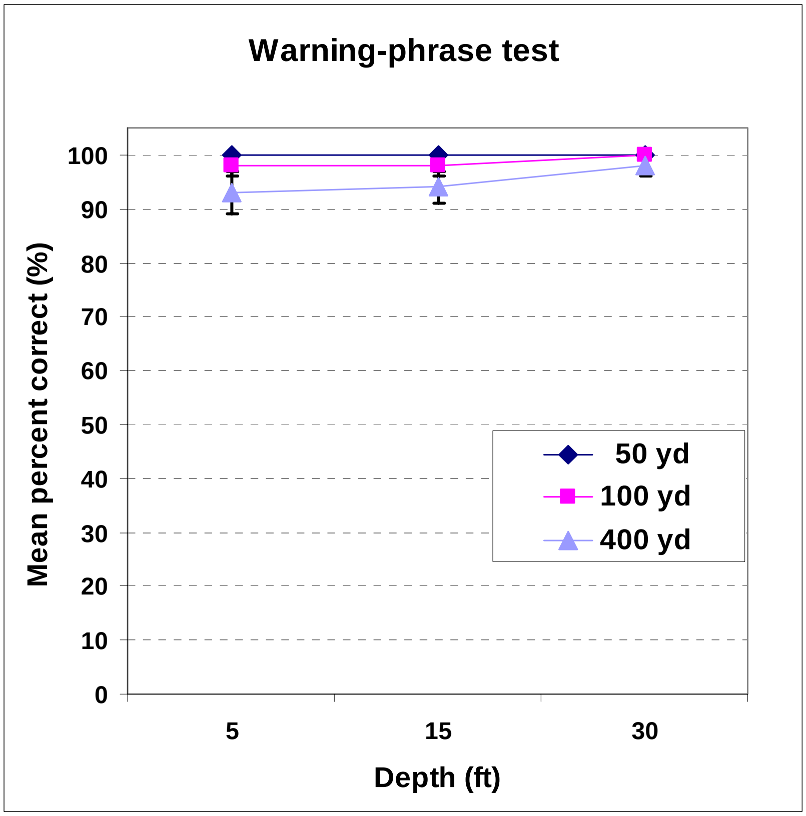


Figure 13. Mean percent correct of warning-phrase identification as a function of diver depth, with the range of the diver from the source as a parameter.

Figure 14 presents the mean percent correct of both phrases and single words as a function of range. Results from these tests support the common notion that phrases are more easily understood than are single words. At the simplest level, this difference can be explained by the increased context provided by a phrase over that of a single word.

A thorough description of the speech intelligibility testing and results is provided in the NSMRL report on the intelligibility testing (see APPENDIX D).

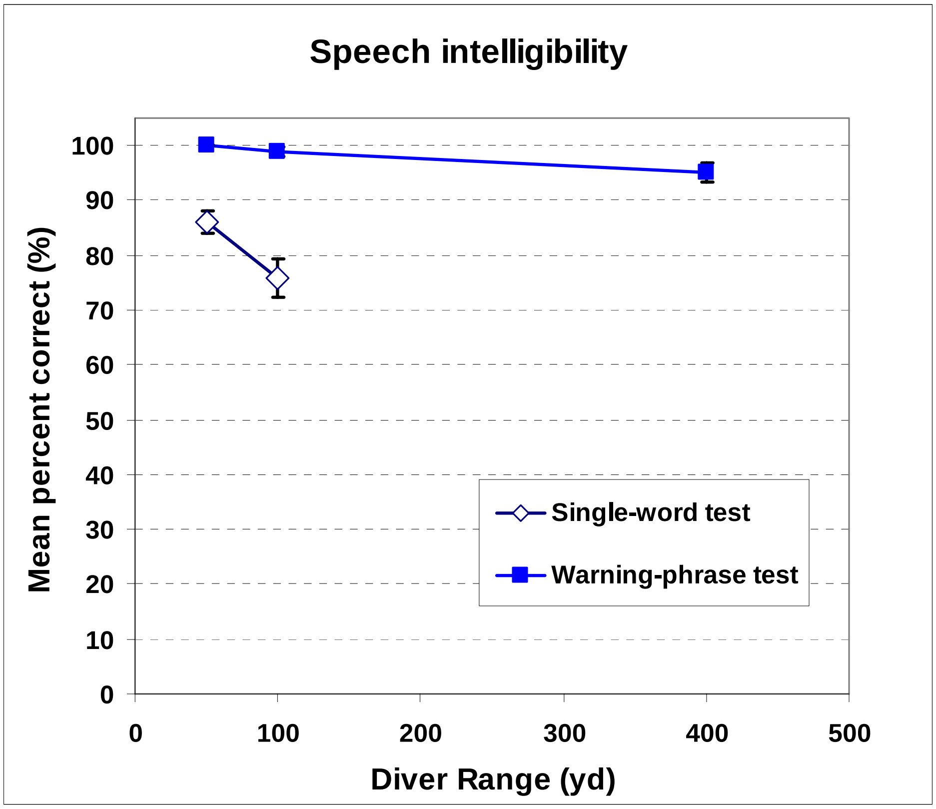


Figure 14. Mean percent correct identification as a function of the range of the diver from the source, with the type of speech material as a parameter.

4.5 *e*LOUD™ vs. Requirements

Table 3 provides an assessment of the *e*LOUD™ system relative to the requirements described in Section 2. These requirements were established by the CG and were incorporated into the development contract.

Table 3. Comparison of system requirements and *e*LOUD™ characteristics.

System Requirement	*e*LOUD™ Characteristic
It must transmit, or otherwise communicate, clear and proven intelligible commands automatically and continuously in English, to an underwater swimmer at a minimum distance of 500 yards from a protected asset, or from a security-zone patrol vessel, to a minimum water depth of 130 ft.	*e*LOUD™ testing confirmed it can transmit tones and voice messages such that they are loud enough to be detected by a hooded diver with open-circuit breathing apparatus at a range of 500 yards or greater. The *e*LOUD™ transducers have resonances at 500 and 2700 Hz, which are used to transmit a custom hi/lo siren tone. The 300 to 4000-Hz band is used to transmit voice messages, including critical frequencies for intelligibility of voice messages. Diver safety issues, and the lack of sufficient water depth in the test area, did not allow performance testing to 130 ft.
It must have the capability to easily add languages other than English, and will be equipped with a microphone for use by security forces.	*e*LOUD™ uses a PDA computer running Microsoft® Windows Mobile™ 5.0. This provides a graphical user interface with a touch screen. A 256-MB SD card stores both the application program and approximately 185 one-minute long messages in any language (3+ hours). The microphone has a volume control and can be used to transmit live messages, or to record new messages for playback. Messages recorded on other systems can be downloaded to *e*LOUD™, by copying the Wave-formatted sound file to the removable SD card.
It must be transportable by one person and easy to operate.	*e*LOUD™ consists of two cases. One case is the control unit containing the PDA, battery, amplifier, and other electronics. The second case holds the transducers and AC battery charger. The complete system can be carried by one person. The control and transducer boxes weigh 35 lb and 25 lb, respectively. The operation of the PDA software is straightforward, and is similar to a typical music MP3 player. The microphone uses a standard Push-to-Talk (PTT) button.
The system control unit must be rugged for operation in harsh salt water and shock environments, waterproof to at least 3 feet underwater when closed, and splash-proof when open and connected for operation.	Rugged plastic resin cases are used for the *e*LOUD™ control and transducer boxes. These cases are waterproof to at least 3 ft when closed, per manufacturer's specifications. When the control box is open, the front panel is splash proof. The PDA uses a water-resistant flexible cover that allows use of the touch screen. Both boxes have a manual air purge valve for air shipping. The buttons and connectors are also splash proof by means of gaskets and/or sealant. The front panel connectors are supplied with protective caps to prevent water accumulation when not in use.
It shall include a waterproof cable at least 75 feet in length, for connecting a control box and the transducer.	The *e*LOUD™ transducers have a 75-ft cable as measured from the top of the topmost transducer. The wet end of the cable is directly connected to the transducers via a waterproof strain relief. The dry end of the cable has a connector that mates with the *e*LOUD™ control box.
The transducer shall be suitable for operating in depths down to 30 feet.	The transducers are rated for operation up to 130 ft deep, although a practical limit is 75 ft, due to the cable length.

Table 3 (cont'd). Comparison of system requirements and *e*LOUD™ characteristics.

System Requirement	*e*LOUD™ Characteristic
It shall have an internal battery to power the complete system for at least 2 hours, and is rechargeable using standard 115 VAC. It will have the capability to operate directly from vehicle or vessel 12 VDC power. The contractor shall determine the system hardware necessary to support continuous operations, including the length of time required to recharge each battery, and the number of batteries needed. Ideally the system will both operate and recharge from either 12 VDC or 115 VAC power.	The *e*LOUD™ system uses a 12-amp-hour (Ah) sealed lead acid battery. During testing, the unit operated continuously (~35%duty cycle) for over 4 hours on this battery. This type of battery can withstand many charging cycles, can operate in any orientation, does not vent any gases, and is suitable for air shipping. A waterproof liquid crystal display (LCD) voltmeter constantly displays the battery voltage. An external, water-resistant charger is used to both charge the battery and to provide power by means of 115 VAC. AC powering requires the battery to remain installed (it acts like a capacitor). Direct 12 VDC boat or vehicle power can also be supplied by way of a separate cable, with a cigarette-lighter plug. During testing, an external auto or marine battery was used for continuous operations away from AC power. This approach is recommended versus switching out the internal battery, which requires the case to be opened. APS provided the following estimates for duration of the 12-Ah battery: 9.00 hours at 15% duty cycle 5.50 hours at 25% duty cycle 3.75 hours at 35% duty cycle Recharge time depends on battery drain. At 25% duty cycle: The following estimates apply: <u>Hours of use</u> <u>Approx. Recharge Hours</u> 1 1.75 2 3.50 3 5.25 4 7.00
It shall be deployable from shore (dock or pier), or from a small patrol boat. If not omni-directional, a lone operator shall be able to aim the underwater loudhailer prototype sound projector when deployed.	The *e*LOUD™ system uses a vertical array of 3 transducers. The total transducer weight is 16 lb without a ballast weight, and is therefore easily deployable. A 1/4" nylon rope is the strength member that connects to the transducers, and can be secured top-side to a cleat or piling. The transducers have an omni-directional horizontal beam pattern and do not have to be aimed at a target. However, excessive tilt of the transducers from vertical (>15 degrees) might cause some signal loss. A ballast weight (10 to 15 lbs) attached to the bottom of the array is recommended if there is any motion through the water due to current or boat motion. The transducers should not be towed.
It will have the capability of attaching an above water speaker for operator monitoring, and to broadcast the messages.	The control box has two gold-plated RCA female jacks on the front for connecting the supplied external speaker. One connector comes directly out of the PDA; the other is a reduced version of the signal output from the amplifier. Either connection can be used for operator monitoring. The output may also be connected to the input of a topside loudhailer, or a PA system, to broadcast the same messages in air.

Table 3 (cont'd). Comparison of system requirements and *e*LOUD™ characteristics.

System Requirement	*e*LOUD™ Characteristic
It is not to be harmful to any living aquatic species, with environmental assessment performed prior to saltwater testing addressing the proposed frequencies and sound pressure levels or other environmental considerations.	An environmental study was completed for proposed testing in the Thames River, CT, which resulted in a "no effects" conclusion for testing with a source level up to a 190 dB in the 500- to 3000-Hz frequency band.

4.6 Operational Assessment

The loudhailer design evolved through four versions. Each design iteration incorporated information from test results and government feedback. For example, Version 1.0 was qualitatively assessed during the June 2005 field test by the NUWC operator. This assessment considered five aspects: Packaging, Wet End, Deck Unit, Connectors/Jacks, and Power/Internal. Comments from this evaluation are presented at the end of APPENDIX B. Several of the issues of concern were addressed in Version 1.1.

The 20 prototype units (Version 1.2) built under the contract option will be distributed for operational use and evaluation by various United States Navy (USN) and CG units. It is anticipated that this first evaluation by operational forces will provide critical feedback on all aspects of the *e*LOUD™ for consideration in the next version build.

Environmental, safety, health, transportation, and communications-spectrum issues were assessed, and these results are presented below.

4.6.1 Environmental Issues

The primary environmental issue for *e*LOUD™ concerns transmitting underwater sound in marine environments where there could be potential impact on humans, marine mammals, fish, or other aquatic species. A draft environmental-awareness study (Labak, 2005) completed as part of this contract suggested that a "no effects" conclusion might be drawn in certain operational areas, depending on the marine mammal population and the duration of system use. The study considered the Endangered Species Act, the Marine Mammal Protection Act, and the Magnuson-Stevens Fisheries Conservation and Management Act. This study was limited to certain areas of the Thames River in Connecticut, based on preliminary plans for testing *e*LOUD™ in this area.

The environmental study process has revealed the importance of the system concept of operations (CONOPS) in assessing the true impact on the environment. In the case of *e*LOUD™ use by the CG, the system will only be energized in response to a threat detection, so the planned operational time is actually quite short (tens of minutes per event, for example). This operational concept results in significantly less environmental impact than would be the case under a

scenario in which the system broadcasts continuously for extended periods (hours or days) as a means of deterrence.

4.6.2 Safety and Health Issues

The primary safety issues for those operating *e*LOUD™, or those in the vicinity of operation, include:

- Unwanted exposure to high levels of sound both underwater and in air
- Unwanted exposure to high voltage levels

The *e*LOUD™ transducer array uses high AC electrical excitation, up to 500V RMS. Exposure to these high voltage levels could be potentially fatal. Version 1.2 has an engraved warning label as shown in Figure 6, and warnings are clearly marked in the User's Manual (APPENDIX F). The output connectors have threaded covers and do not have exposed pins to reduce accidental human contact with high voltage levels.

Improper operation of the *e*LOUD™ system could be potentially dangerous. The message format for all versions up through 1.1 included a hi/lo siren that used a 500-Hz tone for the low-frequency tone. Previously established guidance by NSMRL for the permitted exposure level to divers for this frequency required a 50-yard safety zone around the transducers. In Version 1.2, the low frequency was shifted up to 550 Hz, so that the safety zone could be reduced to 25 yards, also in accordance with NSMRL guidance. This zone reduction was consistent with the established safety zone around the primary detection sonar used in the IAS. Inside this range, discomfort and potential physiological problems could occur. High power operation in air at close ranges could also potentially cause hearing discomfort. Training is required to safely operate the *e*LOUD™ system.

The majority of components of the *e*LOUD™ system are non-toxic. The sealed lead acid main battery is recyclable, and is considered non-hazardous with regard to transportation. As with many underwater transducers, the ceramics in the transducers contain lead, zirconate, and titanate, and should be disposed of in accordance with local regulations. The copper wiring, plastic cases, aluminum mounting brackets, and connectors are non-toxic, and can be recycled. The electronics (PDA, amplifier, and transformer) are essentially consumer electronics, and can be recycled or disposed of in accordance with local or state regulations.

4.6.3 Transportation Issues

No transportation issues are expected with the *e*LOUD™ system. The 12-Ah sealed lead acid battery in each *e*LOUD™ control unit is considered non-spillable and therefore exempt under Code of Federal Register (CFR) 49, 173.159, and needs only to be packaged in a way that prevents short circuiting. The battery is fuse-protected as installed in the *e*LOUD™ system. The *e*LOUD™ cases have purge valves, which should be opened for air shipping.

4.6.4 Communications Spectrum:

The *e*LOUD™ system is not a radio frequency (RF) transmission system, and should not cause RF interference. The PDA and power amplifier are consumer components. The custom circuit board in the *e*LOUD™ system operates on DC power, and contains only audio-frequency (200- to 5000-Hz) signals.

5. CONCLUSIONS AND RECOMMENDATIONS

This report provides a summary of the development and testing of an enhanced underwater loudhailer designed for port security applications. The requirement was for a one-way diver-communication device, with an effective range of 500 yards, to support enforcement of security zones around high-value maritime assets. The performance of the device was evaluated on the basis of a series of acoustic measurements, and in-water testing using divers in a saltwater environment typical of a commercial U.S. port. The following conclusions and recommendations are offered as a result of this work:

<u>1a. Conclusion</u>: Test results show that the *e*LOUD™ produced acoustic transmissions with sufficient power and spectral content to be recognized and understood by hooded, open-circuit divers in a saltwater port-like environment. Findings of the formal intelligibility test indicate that the loudhailer transmitted a closed set of verbal warning phrases to divers at a range of 400 yards, with greater than 90 percent intelligibility. On the basis of measured SPL at longer ranges, NSMRL experts concluded that adequate intelligibility (approximately 85 percent) by divers of warning phrases is possible to ranges of 500 yards, in conditions similar to those during the test. Informal testing with a limited number of divers under acoustically favorable conditions resulted in very high (greater than 90 percent) intelligibility of warning phrases at 600 yards. These results represent an order of magnitude improvement in effective range over the Diver Recall System currently in use by the CG.

<u>1b. Recommendation</u>: Deploy the *e*LOUD™ enhanced underwater loudhailer prototype units for use and evaluation by operational forces. Encourage initial users to complete the loudhailer prototype evaluation form. Incorporate user feedback and other improvements that might be implemented by the vendor in their development and commercialization process into any procurement decisions for additional loudhailers. Timely feedback of evaluation comments will be factored into the vendor's plan for transitioning this technology to small and medium production levels.

<u>2a. Conclusion</u>: The acoustic performance of the enhanced loudhailer is principally a function of the distance between the source (*e*LOUD™ transducer array) and the receiver (diver). The performance is generally independent of the depth of either the source or the receiver (down to 30 feet), or the relative bearing between the two (i.e., the loudhailer output is essentially omni-directional in the horizontal plane).

<u>2b. Recommendation:</u> In an operational situation, deploy the loudhailer transducer array in a strategic location relative to the protected asset and the command center, recognizing the limitations imposed by the transducer cable length. Provide a standoff of 10 ft or more from underwater physical structures, such as ship hulls, pier pilings or bulkheads, to avoid unwanted blockage and reflections of the signal. The center transducer of the array should be deployed to mid-water depth, but not generally deeper than 20 feet. Deeper deployments of the transducers might result in unacceptably low sound levels near the surface. Areas with large tidal ranges will require special attention in order to maintain the proper deployment depth. The device is omni-directional in the horizontal direction, so it does not need to be aimed. A ballast weight of 10 to

15 pounds is recommended to maintain a nominally vertical array orientation (i.e., less than 15 degrees tilt).

3a. Conclusion: The environment can have a significant effect on the performance of an acoustic device. There are several factors that should be considered in assessing potential loudhailer performance. Some of these factors are relatively constant, while others will vary with time or space. The principal factors include: the physical environment (bottom topography and composition, physical structures, currents); the sound velocity profile (SVP), which is predominantly driven by the vertical temperature profile; and the background noise level.

3b. Recommendation: Operators should be trained to assess the environment with respect to acoustic-transmission conditions, how to deal with them, and how they will impact performance. The physical environment can be assessed through published information (charts, site plans, and current tables), or by direct observation. The SVP or vertical temperature profile can be measured and fed into a computer program for performance modeling. This capability would also support the performance assessment of other acoustic components of the IAS, such as the detection sonar. It is recommended that units with an *e*LOUD™ and an IAS acquire this acoustic performance-modeling capability, and that it be automated to the greatest extent possible. The background noise might be comprised of both natural/biological noise, such as that generated by snapping shrimp or waves, and man-made noise due to vessel traffic, underwater construction, etc. Operators should seek to minimize the noise sources where possible. One example is to operate response boats in a way that minimizes their contribution to the noise level. Extreme noise levels might require modification of normal operating procedures, by increasing output power where possible, or by moving the source closer to the intended receiver.

4a. Conclusion: A 200-watt amplifier was used in Version 1.0 of the loudhailer versus a 300-watt amplifier used in Version 0.0. Both were class AB amplifiers, which have a low efficiency (22 percent). During field testing of Version 1.0, some audio distortion was noted in the recordings; this was later attributed to the transformer used to match the amplifier in this version.

4b. Recommendation: To address audio distortion, a change of amplifier and matching transformer has been implemented in Version 1.2 and incorporated into the system specifications. The system now uses a new 400-watt Class D amplifier, which was not available earlier. This amplifier exhibits a high efficiency (88 percent), in a size comparable to the earlier 200-watt amplifier. The net result is twice the power and four times the efficiency, which should provide improved acoustic performance, eliminate the distortion, and increase operating time on the internal battery.

5a. Conclusion: Due to practical constraints, intelligibility testing with single words was limited to ranges of 50 and 100 yards. Approximately 90 percent of single words at 50 yards, and 70 percent of single words at 100 yards, were correctly understood. The overall results for single words were less than those for phrases, and decreased with range more quickly. Depth was an unexpected factor in the intelligibility testing of single words, and is so far unexplained. Nonetheless, NSMRL experts suggest that the results for single word testing are useful in providing a reasonable lower bound in estimating the effectiveness of live-transmissions when

using the system microphone. This is because the content of a live transmission might be unexpected or out of context. With a live transmission, there is little or no quality control on the voice level, tenor, or pace, and there is no signal conditioning for optimal reception underwater. These conditions are best approximated by the single word testing.

<u>5b. Recommendation</u>: For best results, operators should use prerecorded messages whenever possible. If an existing prerecorded message is not suitable, the second preference is to record, condition, and save a message using the PDA, and then broadcast it in the same way a prerecorded message is broadcast. Results of this approach are expected to fall between those for prerecorded broadcasts and live transmissions. If urgency and the situation dictate, live transmissions may be used, with the lower bound of results approximated by the intelligibility of single words, as described above. If time allows, it is recommended that live transmissions also be repeated to enhance intelligibility. The use of live transmissions would be most acceptable at shorter ranges. Operators should be trained to speak clearly, as in the case of radio transmissions, and should exercise the live-transmission mode with divers in the water for feedback. Use of both male and female voices is recommended.

<u>6a. Conclusion</u>: The parameters of the loudhailer test matrix were limited, due to resource and time constraints. These limitations should be recognized when considering the conclusions and recommendations of this report. The most significant of these factors follow:

- The intelligibility testing used only native speakers of American English. In-air speech tests have shown that non-native speakers have greater difficulty than do native speakers in understanding speech in complex auditory environments. This reality could result in a significant reduction in intelligibility. The non-native speaker deficit reasonably translates to the underwater environment.
- The intelligibility testing used only American-English source material for stimuli. These results should be applicable to other Romance languages, but might not necessarily apply to languages with significantly different phonemic qualities, such as Korean, Chinese, or Arabic. Further study is required to assess intelligibility of these languages when they are broadcast to divers using *e*LOUD™.
- The intelligibility testing used only a single presentation of the test message. A message format that is repeated can contribute to the overall intelligibility. A message that is familiar can also contribute to intelligibility.
- The noise level of the test environment was relatively low compared to that of many busy commercial ports. If *e*LOUD™ is deployed in a high noise environment, a reduction in intelligibility and effective range can be expected.

<u>6b. Recommendation</u>: Operators should be made aware of these factors and how they can influence the intelligibility and range of *e*LOUD™ transmissions. It is recommended that the format of the warning messages continue to incorporate an initial hi/lo siren, using tones centered on 2700 Hz and 550 Hz, a brief message, another hi/lo siren, and a repeat of the message. Operators may also incorporate both male and female voices in this format, if desired, in light of the anecdotal evidence supporting the use of female voices. Prerecorded foreign language messages should be developed professionally, and be of the same high quality as the

English messages. It is recommended that a public outreach campaign be used to advertise audible versions of these prerecorded messages throughout the recreational, commercial, and military dive communities, to allow them to become familiar with the messages, their content and appropriate responses. Further testing is recommended if a better understanding of the impact of high background noise on operational performance and effective range is required.

<u>7a. Conclusion</u>: *e*LOUD™ is a high-powered acoustic transmission device, and must be operated in accordance with recommended safety procedures to avoid injury. High-voltage (greater than 500V) is present on the control unit front panel cable connector pins, and in the transducer cable when connected. High sound pressure levels are present in the immediate vicinity of the transducers when the unit is broadcasting. During testing, divers observed a 50-yard safety zone, and reported no physical discomfort at a range of 50 yards.

<u>7b. Recommendation</u>: Operators should observe all safety precautions as detailed in the User's Manual (APPENDIX F). The low-frequency component of the message siren has been adjusted away from the 500-Hz tone, which was known to present a higher risk to divers than does the 550-Hz tone now used. The loudhailer should not be operated in air, in a pool, or in other enclosed areas, or when a friendly diver is less than 25 yards from the transducer. Both the Main Power and Transmit Enable switches should be OFF before the transducer cable is connected or disconnected. The loudhailer should never be operated with a damaged cable. See the User's Manual (APPENDIX F) for a full list of safety precautions.

6. REFERENCES

Abraham, B. (2004a). Underwater Loudhailer Acoustic Requirements Analysis. TSWG Contract W91CRB-04-C-0057 report. Unpublished work. Applied Physical Sciences Corp.

Abraham, B. (2004b). Underwater Loudhailer Power and Charging Subsystem Design. TSWG Contract W91CRB-04-C-0057 report. Unpublished work. Applied Physical Sciences Corp.

Abraham, B. (2005). Underwater Loudhailer Transducer Final Design Report. TSWG Contract W91CRB-04-C-0057 report. Unpublished work. Applied Physical Sciences Corp.

Labak, S. J. (2005). "Environmental Assessment (EA) for the Underwater Loudhailer Sea Test", TSWG Contract W91CRB-04-C-0057. Unpublished work. Marine Acoustics Inc.

Rehn, K, Lent, K. and Ruckel, J. (2004). Diver Recall Device Evaluation. The University of Texas at Austin Applied Research Laboratories report for the Defense Threat Reduction Agency (For Official Use Only).

(This page intentionally left blank.)

APPENDIX A.

UNDERWATER LOUDHAILER
PROTOTYPE TEST REPORT

Draft
May 18, 2005

Revised
September 30, 2005

TSWG Contract W91CRB-04-C-0057
CDRL Data Item A009

Prepared by:
Bruce Abraham, Ph.D.
Applied Physical Sciences Corp
2 State Street, Suite 300
New London, CT 06320
Phone: 860-440-3253 x104
Fax: 860-440-3075
Email: babraham@aphysci.com

Introduction

This report summarizes underwater loudhailer initial prototype testing that was conducted during the week of 7-11 March 2005 at the Naval Undersea Warfare Center Division Newport (NUWCDIVNPT). The purpose of the test was to quantitatively measure acoustic performance of the initial prototype in support of its final design and field testing. The underwater loudhailer is an underwater audio transmission system designed to communicate warning tones and clear messages to divers in a restricted area before adverse action is taken. Prior to the prototype testing, several electro-acoustic tests had been performed at the NUWCDIVNPT Dodge Pond Acoustic Test Facility. The underwater loudhailer initial design had been performed by APS and the Preliminary Design Review (PDR) had been completed in January 2005.

Initial Prototype Description

The underwater loudhailer initial prototype developed for this test consisted of a number of custom and commercial off-the-shelf (COTS) components. The primary power components were a COTS 300W RMS audio amplifier supplied by a 12 Ah sealed lead acid battery. The PDR called for a custom Class D amplifier but this could not be completed in time for the testing. The use of the COTS Class AB amplifier did not detract from the test results and its major impact was on the size of the Loudhailer control unit enclosure. The “brain” of the prototype was an HP iPAQ 2215 Personal Digital Assistant (PDA) mounted beneath a splash-proof screen. The PDA had custom software that allowed for warning message selection, playback, and recording. The prototype also had a microphone that allowed for live voice transmission. A picture of the prototype is shown in Figure A-1. The PDA software was controlled via a pen stylus tethered to the control unit. Also on the control unit were a waterproof battery voltage meter, the main power switch, circuit breakers for the amplifier and microphone circuit, carrying handles, and bulkhead connectors for the transducer, microphone, and external power.

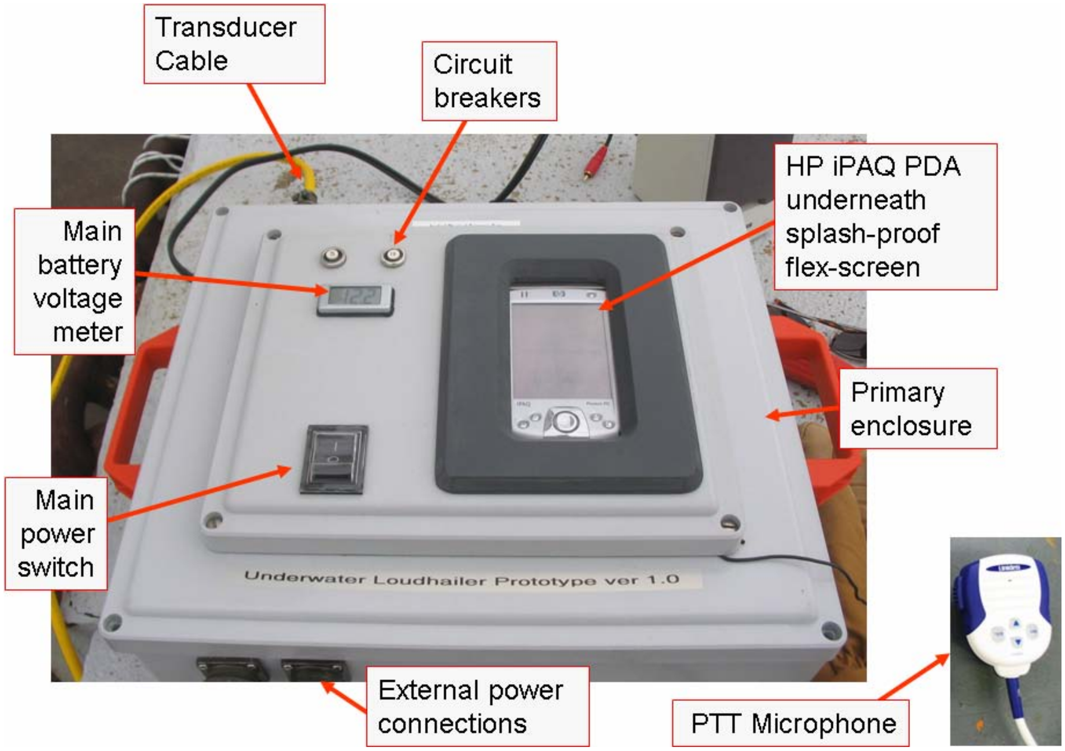


Figure A-1. Underwater loudhailer initial prototype.

The PDA audio output was connected to a custom-built circuit board. The circuit board had a 5V regulator to power the microphone, a preamplifier for the microphone, and a relay for switching the amplifier audio input from the PDA output to the microphone preamplifier output. The default setup was for the PDA audio output to be connected directly to the amplifier input.

The Profile USA AP400 amplifier was wired in a bridged configuration with a rated RMS power output of 300W into 4Ω. The battery was directly connected to the amplifier (which had its own fuse) and the amplifier was enabled via a separate trigger connected to the main power switch. An Edcor transformer was used to step-up the voltage approximately 8-9 times and help match the high impedance of the transducers to the relatively low output impedance of the amplifier.

The transducer array is the “underwater speaker” part of the system. It consisted of three Ocean Engineering Enterprises DRS-8 speakers wired in parallel intended for a vertical line array configuration. The center-to-center spacing of the speakers was 24” and this provided array directivity index to boost the transmitted signal. A picture of the transducer array is shown in Figure A-2 during deployment. The transducers have well-damped resonances at 500 and 2700 Hz when operated in water (the 2700 Hz resonances moves higher in air). This provides a good frequency band over which voice messages can be effectively transmitted. More details of the array design are given in reference 0.

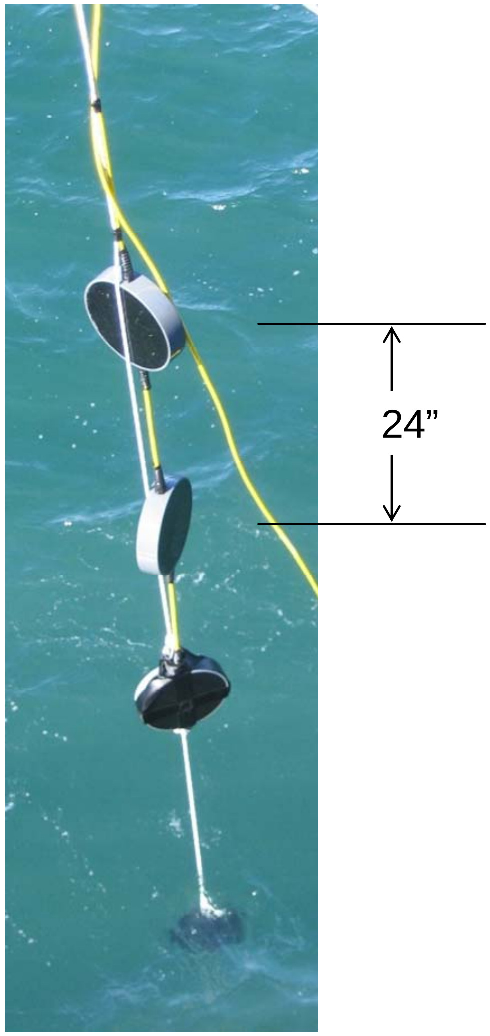


Figure A-2. Loudhailer transducer array during deployment.

An earlier requirements analysis[0] indicated that a source level of approximately 190 dB would be required to effectively reach hooded divers at a range of 500 yds in adverse acoustic propagation conditions (spherical spreading plus 5 dB). The estimate minimum receive level was approximately 130–135 dB which was consistent with earlier results with divers[0]. The prototype system was design to meet this requirement at the 2700 Hz transducer resonance. The concept of operations includes alerting the diver with a warning tone or tones after which he or she would skip-breath to hear the voice messages.

The prototype test was designed to quantitatively measure the sound power output of the prototype Underwater Loudhailer in a real-world shallow-water environment. The NUWCDIVNPT Stillwater Basin was chosen for this reason as it has a depth of 35-50 ft consistent with many harbors and had been used in previous diver warning system tests[0]. Plans were made to measure the sound pressure level (SPL) as a function of frequency, range, source depth, and receive depth. Additionally an initial informal assessment of the system intelligibility was planned using divers listening to tones and example warning phrases. The next section will describe the test details.

Test Setup

Test equipment was set up at the NUWCDIVNPT Stillwater Basin shown in Figure A-3. The loudhailer prototype was deployed from the west end of Pier 1 using an 8-ft long aluminum extension pole to displace it somewhat from the pier pilings. The water depth at the deployment area was nominally 35 ft, so source transducer test depths of 9, 18, and 27 ft were chosen. The loudhailer control unit was set up on the pier and connected to the transducer array. The PDA was used to transmit all test tones, chirps, and other audio signals except live microphone transmissions.

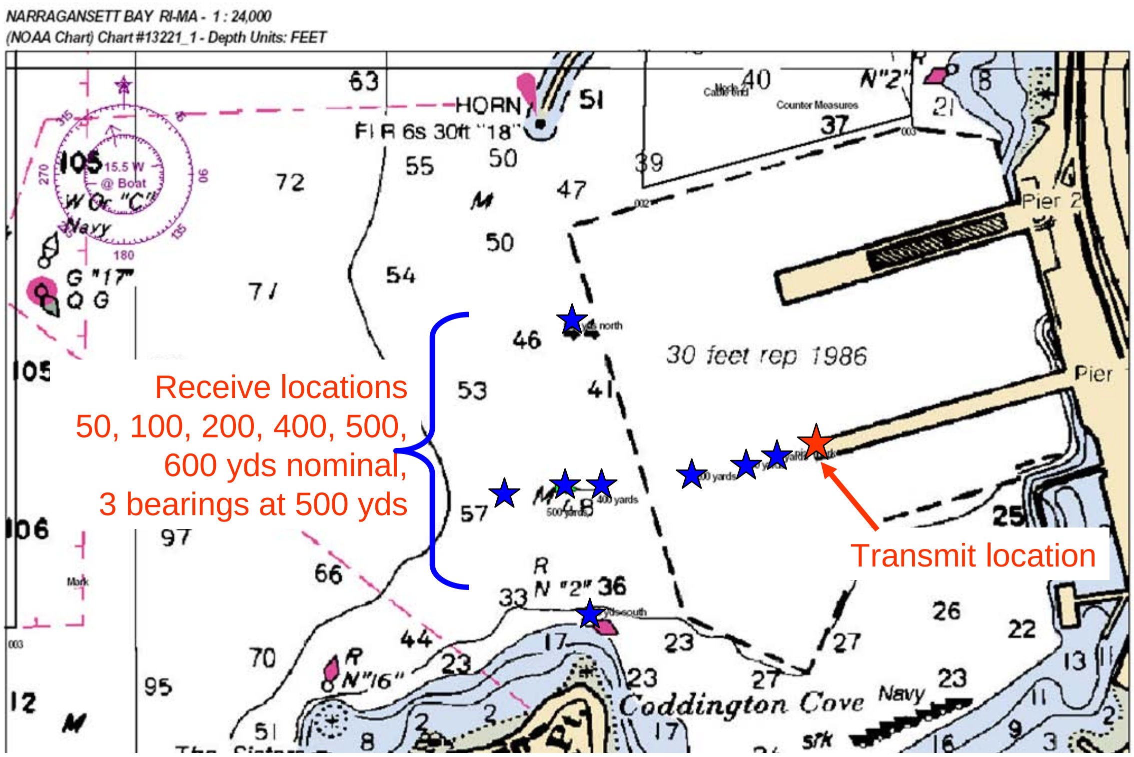


Figure A-3. NUWCDIVNPT Stillwater Basin test area.

A Wilcoxon Research, Inc., H507A hydrophone was used to record the acoustic pressure at several ranges and depths relative to the Loudhailer source transducer array. The hydrophone sensitivity is -180.3 dB re 1 V/µPa. The receive hydrophone was deployed using the NUWCDIVNPT WB30 workboat as shown in Figure A-4. A laser rangefinder and shipboard GPS was used to position the boat at required nominal ranges. The receive hydrophone was cable-tied to a nylon rope with an 8-lb mushroom anchor and lowed to one of four test depths (7.5, 15, 30 and 35 ft). A Mackie 24 bit digital recorder was used to acquire the hydrophone signals and data were stored as 48 kHz Microsoft Wave files. Full-scale signal in the wave file corresponds to a voltage of 13.4 V. Figure A-5 shows the receive hydrophone and recording system used aboard the WB30. Note the WB30 has “clean” 115VAC power supplied by a high-quality inverter.

Figure A-4. NUWCDIVNPT vessel WB30.

Receive Hydrophone and anchor ***Hydrophone Recording System***

Figure A-5. Receive hydrophone and data recording system.

The combination of different source and receiver depths was used to assess the sensitivity of transducer and listener location on overall sound level. Custom MATLAB analysis programs were used to calculate the spectrogram and maximum narrowband and one-third-octave (OTO) sound pressure levels (SPL).

Two-way radios were used to coordinate operations between Pier 1 and the WB30 vessel. For the hydrophone recordings the test sequence was nominally:

- Deploy loudhailer from Pier 1
- Position WB30 at desired Range (WB30 anchors and turns off engines)
- Position receive hydrophone at first depth
- Begin recording (COMEX) and start tone/message audio transmission

- Stop recording (FINEX)
- Position source transducer array at 2nd test depth and repeat recording
- Position source transducer array at 3rd test depth and repeat recording
- Move receive hydrophone to 2nd test depth and repeat set of recordings for 3 source depths
- Repeat for remaining two receive hydrophone locations
- Measure ambient noise at 30 ft depth

For the diver testing, the test sequence was nominally:

- Deploy loudhailer from Pier 1
- Position WB30 at desired Range (WB30 anchors and turns off engines)
- Diver is deployed and receives board with grease pencil and instructions from Master Diver
- When diver is in position at test depth, warning tone and phrase is transmitted and repeated once
- Diver writes down what he/she heard and whether or not a tone was heard
- Diver moves to second test depth and different warning tone and message is transmitted
- Diver surfaces and either a second diver is deployed or the WB30 changes range

Test Results

Testing began on 7 March 2005 at the NUWCDIVNPT Stillwater Basin. Receive locations along a line directly out from Pier 1 were tested at nominal ranges of or 50, 100, 200, 400, and 500 yds. Receive hydrophone depths of 7.5, 15, 30, and 35 ft were used. Table A-1 shows a log for 7 March 2005 testing. The audio transmissions consisted of:

2.7 kHz tone, 4 sec
2.7 kHz tone, 4 sec
500 Hz tone, 4 sec
Linear Chirp 200 – 3500 Hz, 2 sec
Linear Chirp 200 – 3500 Hz, 2 sec
Hi/Lo siren 1, 3 sec
Hi/Lo siren 1, 3 sec
Hi/Lo siren 2, 3 sec
Hi/Lo siren 2, 3 sec

After the sequence of tones, four messages were transmitted including two English phrases, one Spanish phrase, and one Arabic phrase as derived from previous recordings[0].

Table A-1. Underwater loudhailer prototype test log for 7 March 2005.

Run Number	Recorder Take Number	Date	COMEX Time	Source Transducer Depth (ft)	Receive Hydrophone Depth (ft)	Boat Range to Large Sign on Pier (yds)	Boat Latitude (N)	Boat Longitude (W)	CTD Scan	Loudhailer Battery Voltage at COMEX
1	7	3/7/2005	1017	9	7.5	48	41°31.630	71°19.140	Yes near pier	12.7
2	8	3/7/2005	1021	18	7.5	52				12.6
3	9	3/7/2005	1025	27	7.5	56				12.6
4	10	3/7/2005	1030	27	15	55				12.6
5	11	3/7/2005	1034	18	15	56				12.6
6	12	3/7/2005	1038	9	15	52				12.5
7	13	3/7/2005	1042	9	30	51				12.5
8	14	3/7/2005	1046	18	30	56				12.5
9	15	3/7/2005	1049	27	30	51				12.4
9A	16	3/7/2005	1051	n/a	30	53				
10	17	3/7/2005	1055	27	35	56				12.8
11	18	3/7/2005	1058	18	35	58				12.4
12	19	3/7/2005	1102	9	35	57				12.4
13	20	3/7/2005	1121	9	7.5	105	41°31.622	71°19.172	Yes	12.4
14	21	3/7/2005	1123	18	7.5	101				12.4
15	22	3/7/2005	1128	27	7.5	106				12.3
16	23	3/7/2005	1134	27	15	111				12.5
17	24	3/7/2005	1138	18	15	125				12.3
18	25	3/7/2005	1140	9	15	132				12.3
19	26	3/7/2005	1149	9	30	120				12.3
20	27	3/7/2005	1153	18	30	121				12.4
21	28	3/7/2005	1156	27	30	122				12.2
21A	29	3/7/2005	1159	n/a	30	122				
22	30	3/7/2005	1202	27	35	116				12.5
23	31	3/7/2005	1205	18	35	119				12.1
24	32	3/7/2005	1208	9	35	118				12.1
25	33	3/7/2005	1228	9	7.5	200	41°31.599	71°19.232	Yes	12.4
26	34	3/7/2005	1232	18	7.5	201				12.2
27	35	3/7/2005	1235	27	7.5	201				12.2
28	36	3/7/2005	1239	27	15	200				12.2
29	37	3/7/2005	1242	18	15	195				12.1
30	38	3/7/2005	1242	9	15	195				12.1
30-1	39	3/7/2005	1250	9	15	191				
31	40	3/7/2005	1254	18	15	193				12.1
32	41	3/7/2005	1258	27	15	193				12.1
33	42	3/7/2005	1301	27	30	193				12.1
33A	43	3/7/2005	1304	n/a	30					
34	44	3/7/2005	1307	27	35	187				12.1
35	45	3/7/2005	1310	18	35	193				12.1
36	46	3/7/2005	1313	9	35	185				12.1
36A	47	3/7/2005	1314	n/a	35					

Table A-1 (cont'd). Loudhailer Prototype test run list for 7 March.

Run Number	Recorder Take Number	Date	COMEX Time	Source Transducer Depth (ft)	Receive Hydrophone Depth (ft)	Boat Range to Large Sign on Pier (yds)	Boat Latitude (N)	Boat Longitude (W)	CTD Scan	Loudhailer Battery Voltage at COMEX
37	48	3/7/2005	1329	9	7.5	394	41°31.567	71°19.435	Yes	12.2
38	49	3/7/2005	1332	18	7.5	395				12.1
39	50	3/7/2005	1335	27	7.5	391				12.1
40	51	3/7/2005	1339	27	15	295				12.1
41	52	3/7/2005	1342	18	15	392				12.1
42	53	3/7/2005	1345	9	15	393				12.1
43	54	3/7/2005	1350	9	30	395				12.0
44	55	3/7/2005	1352	18	30	392				12.1
45	56	3/7/2005	1355	27	30	393				12.1
45A	57	3/7/2005	1356	n/a	30					
45A-1	58	3/7/2005	1400	n/a	30					12.2
46	59	3/7/2005	1405	27	35	400				12.2
47	60	3/7/2005	1408	18	35	402				12.1
48	61	3/7/2005	1411	9	35	397				12.1
49	62	3/7/2005	1448	9	7.5	505	41°31.599	71°19.232	Yes, twice	12.1
50	63	3/7/2005	1451	18	7.5	507				12.1
51	64	3/7/2005	1455	27	7.5	508				12.0
52	65	3/7/2005	1503	27	15	508				12.1
53	66	3/7/2005	1506	18	15	514				12.0
54	67	3/7/2005	1508	9	15	516				12.0
55	68	3/7/2005	1513	9	30	510				12.1
56	69	3/7/2005	1515	18	30	521				12.0
57	70	3/7/2005	1518	27	30	519				12.0
58	72	3/7/2005	1524	27	35	508				12.0
59	73	3/7/2005	1528	18	35	504				12.0
60	74	3/7/2005	1530	9	35	513				12.0
57A	75	3/7/2005	1535	n/a	30					

The underwater loudhailer prototype was operated at full power on 7 March 2005. The internal 12Ah battery and an external 12VDC marine battery were used to power the loudhailer.

A spectrogram (time/frequency distribution) of the received pressure for a range of 521 yds, 18 18-ft source depth, and 30 ft receive depth is shown in Figure A-6. The frequency content and duration of the tones, chirps, and sirens can be seen in the spectrogram. The sirens consisted of a low frequency "whoop" between 400 and 600 Hz followed by a constant frequency 2.7 kHz tone. Siren 1 had a 0.7 sec repetition rate whereas Siren 2 had a faster 0.3 sec rate. These particular frequencies were chosen because the DRS-8 transducers resonate at both 500 and 2700 Hz.

For each receive/source/range combination, the maximum sound pressure level generated as a function of frequency was calculated from the hydrophone recordings. Figure A-7, Figure A-8, Figure A-9, Figure A-10, and Figure A-11 show the measured maximum OTO SPL at nominal ranges of 50, 100, 200, 400, and 500 yds, respectively. The sound velocity profile for this test is shown in comparison with those recorded during the other tests in Figure A-12. For these propagation conditions, which had a nearly isothermal sound velocity profile, there is approximately +/- 5 dB of variation in the received maximum OTO SPL. Spreading loss at short ranges is nearly spherical (20 log R) whereas loss is less (~17 log R) at the further ranges. This is typical of shallow water sound propagation with a hard bottom.

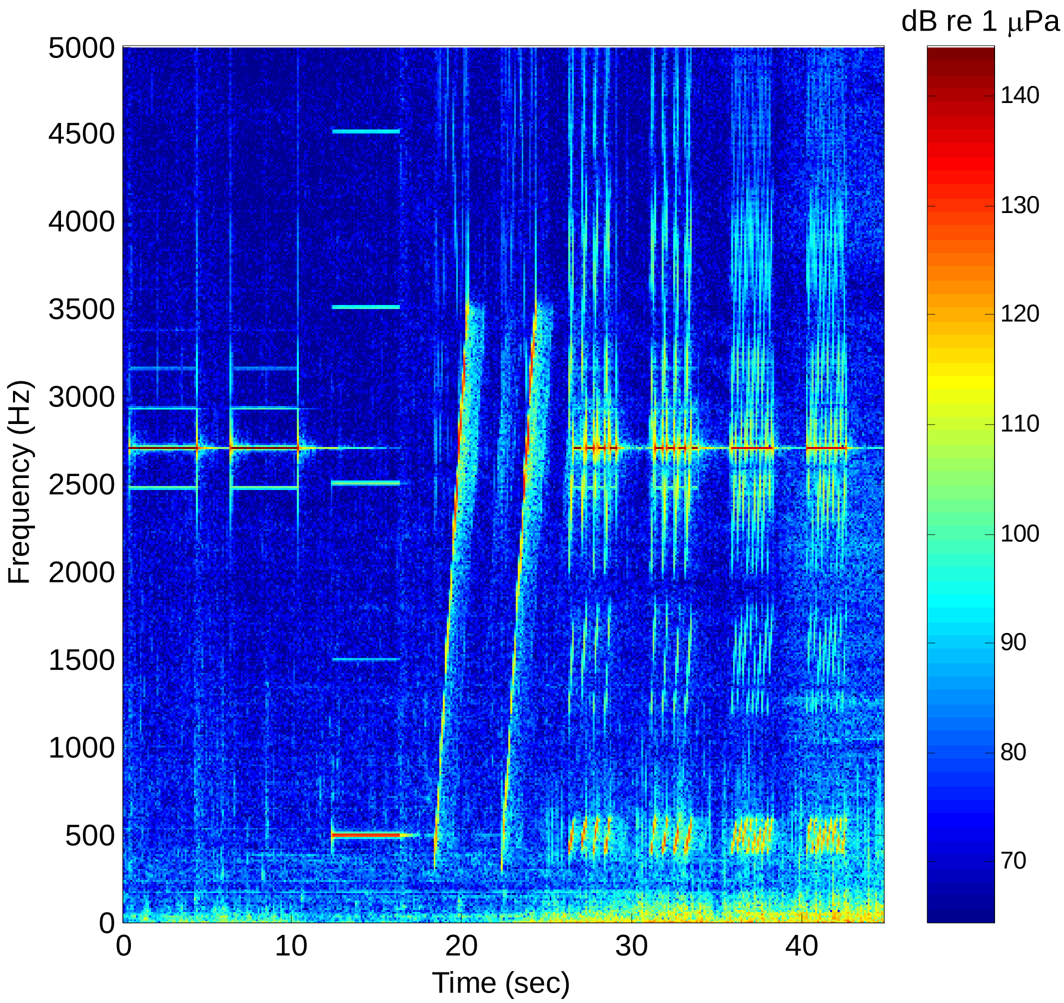


Figure A-6. Spectrogram of receive pressure for tone and siren transmission.

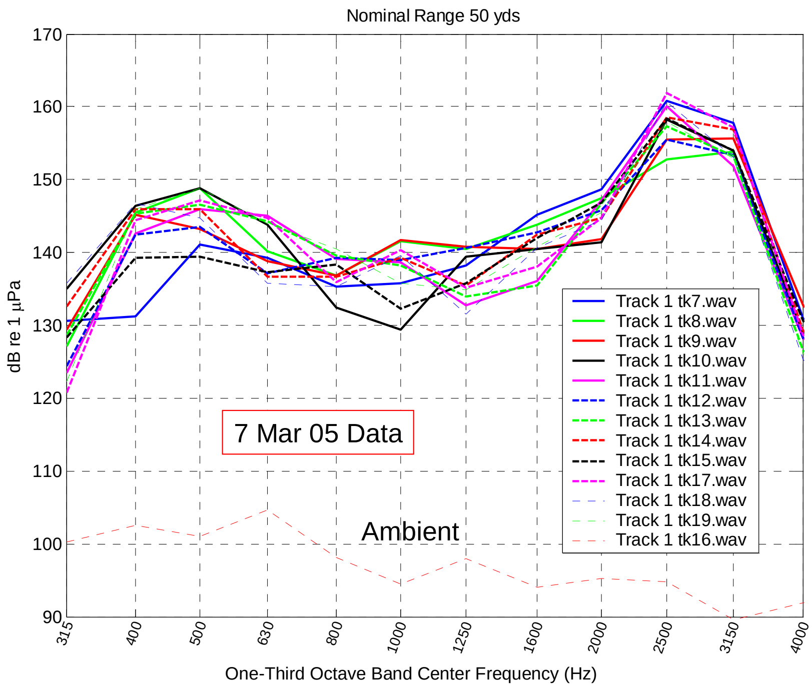


Figure A-7. Maximum receive SPL at 50 yard range.

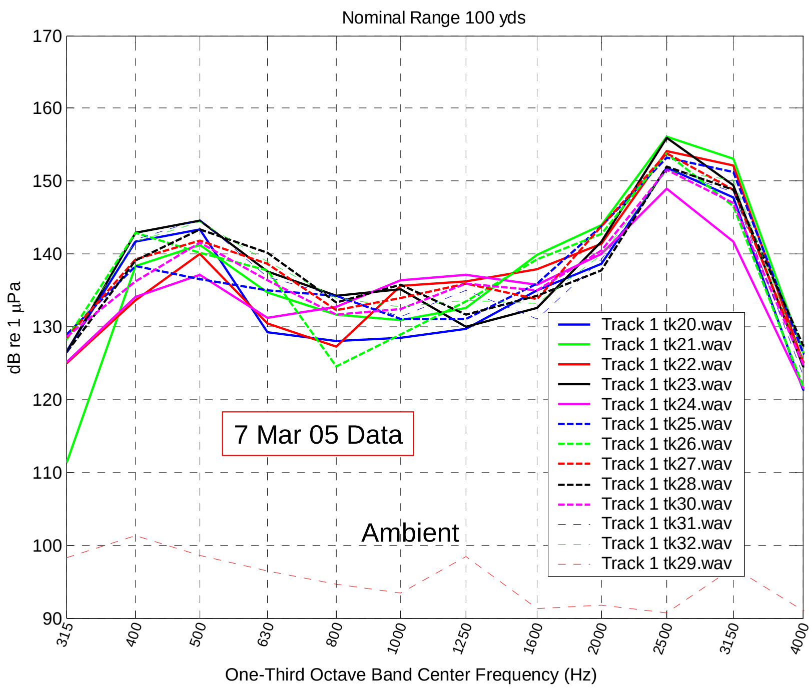


Figure A-8. Maximum receive SPL at 100 yard range.

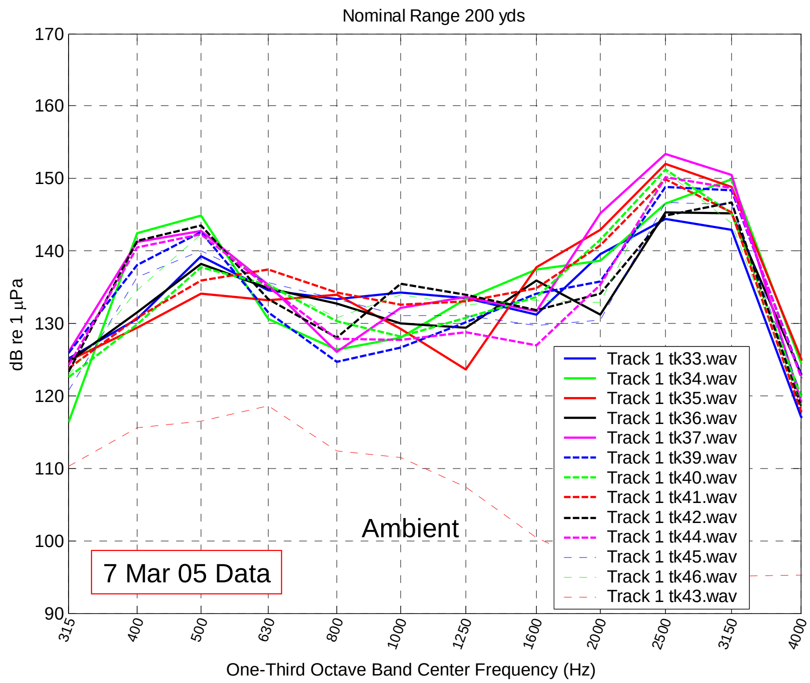


Figure A-9. Maximum receive SPL at 200 yard range.

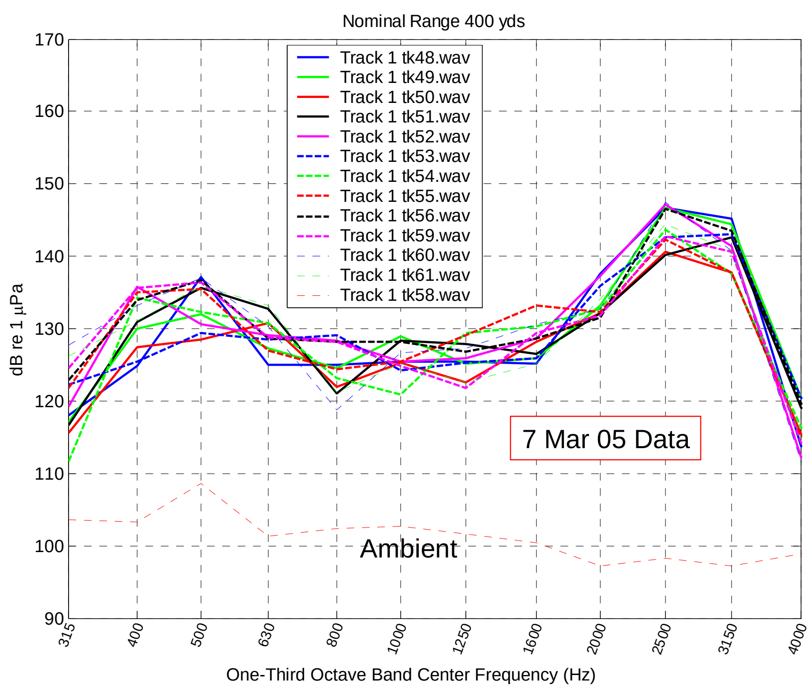


Figure A-10. Maximum receive SPL at 400 yard range.

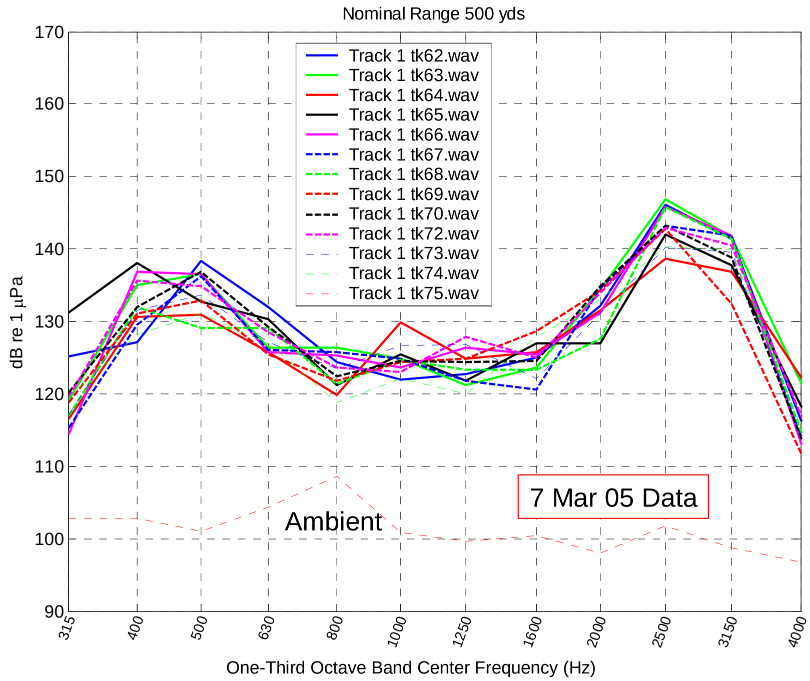


Figure A-11. Maximum receive SPL at 500 yard range.

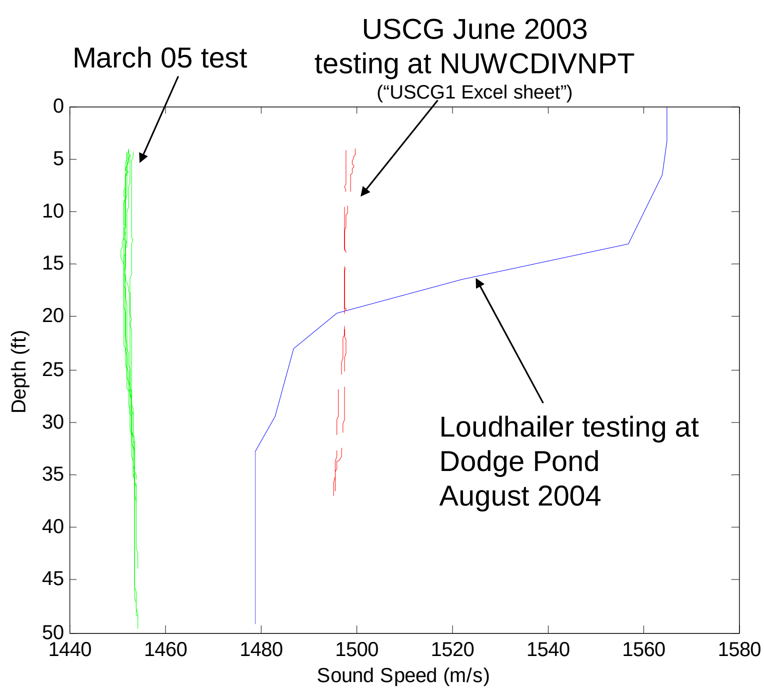


Figure A-12. Sound velocity profiles for Mar 05 test compared with other tests.

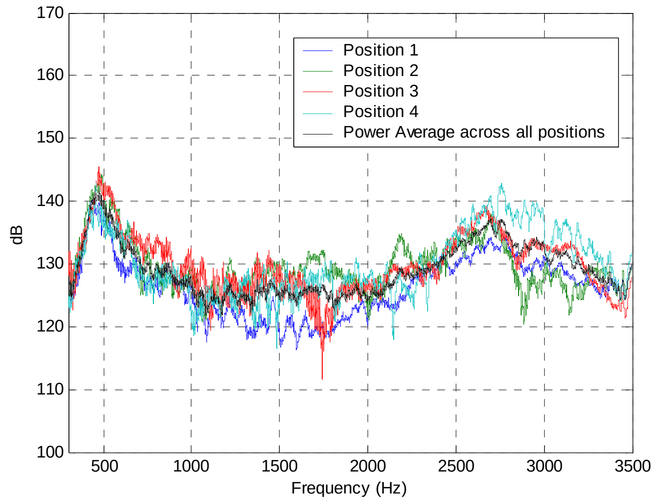
Recall the estimated SPL required to successfully alert a hooded diver was estimated as 130 to 135 dB. The maximum received SPL at 500 yds range was well above this so we would expect divers to be able to hear the warning tones even in the presence of regulator noise.

Additional tests were conducted on 8 Mar 05 using different receive locations and a log is provided in Table A-2. Test locations were further south (toward a shoal) of the 7 March 2005 locations and also further north (toward a breakwater).

Table A-2. Underwater loudhailer prototype test log for 8 March 05.

Run Number	Recorder Take Number	Date	COMEX Time	Source Transducer Depth (ft)	Receive Hydrophone Depth (ft)	Boat Range to Large Sign on Pier (yds)	Boat Latitude (N)	Boat Longitude (W)	CTD Scan	Loudhailer Battery Voltage at COMEX	Comments / Conditions
61	2	3/8/2005	0827	9	7.5	502	41°31.583	71°19.436	Yes	12.8	Hydrophone isolated from rope with open-cell foam, Boat at 500 yd position from 7 Mar 05
62	3	3/8/2005	0831	18	7.5					12.8	Windy, raining
63	4	3/8/2005	0835	27	7.5	502				12.8	NOTE ALL 8 MAR 05 RUNS HAD LOUDHAILER AT 60% VOLUME FOR WINDOWS VOLUME SETTING (100% FOR LOUDHAILER LABVIEW PROGRAM)
64	5	3/8/2005	0839	27	15	500				12.8	Quiet, no bumps on hydrophone
65	6	3/8/2005	0843	18	15	511				12.7	
66	7	3/8/2005	0847	9	15	502				12.7	
67	8	3/8/2005	0850	9	30	507				12.7	
68	9	3/8/2005	0854	18	30	511				12.6	
69	10	3/8/2005	0857	27	30	512				12.6	
69A	11	3/8/2005	0900	n/a	30	513				n/a	
70	12	3/8/2005	0903	27	35	512				12.6	
71	13	3/8/2005	0907	18	35	516				12.5	
72	14	3/8/2005	0911	9	35					12.5	508
68V	15	3/8/2005	0917	18	15	510					Live voice transmission
73	16	3/8/2005	0933	18	15	498	41°31.480	71°19.371		12.5	New position closer to Naval War College
74	17	3/8/2005	0937	27	15	498				12.4	
75	18	3/8/2005	0941	27	30	496				12.4	
76	19	3/8/2005	0944	18	30	496				12.4	
76A	20	3/8/2005	0947	n/a	30					n/a	
76V	21	3/8/2005	0951	18	30	496					497
77	22	3/8/2005	1007	18	15	500	41°31.439	71°19.313		12.3	New position even farther East
78	23	3/8/2005	1010	27	15					12.3	
79	24	3/8/2005	1013	27	30	502				12.3	
80	25	3/8/2005	1017	18	30	504				12.2	
80A	26	3/8/2005	1020	n/a	30	504				n/a	
80V	27	3/8/2005	1022	18	30					12.2	502
81	29	3/8/2005	1049	18	15	516	41°31.846	71°19.269		12.3	New position between breakwater and Pier 1
82	30	3/8/2005	1053	27	15	512				12.2	
83	31	3/8/2005	1057	27	30	512				12.2	
84	32	3/8/2005	1100	18	30	512				12.1	513
84A	33	3/8/2005	1103	n/a	30	513				n/a	
84V	34	3/8/2005	1106	18	30	513					Voice cutting out (amp overload)
85V	35	3/8/2005	1108	18	30						Voice repeat, talking softer
86	36	3/8/2005	1129	18	15	596	41°31.549	71°19.488		12.0	New position along original radial line, 600 yd
87	37	3/8/2005	1133	27	15	596				12.0	Raining, lots of cable strumming in current
88	38	3/8/2005	1137	27	30					12.1	
89	39	3/8/2005	1141	18	30	602				12.1	
89A	40	3/8/2005	1144	n/a	30	602				n/a	Raining
89V	41	3/8/2005	1146	18	30					12.2	

Except for inadvertently setting the PDA volume 12 dB lower than the 7 March 2005 testing, the spatial variations in the received pressure field were not significant as shown in Figure A-13.



Position 1: Baseline position (~45 ft water depth)
Position 2: SE towards NETC
Position 3: Further SE
Position 4: Between breakwater and Pier 1

Figure A-13. Measured narrowband SPL at different receive bearings, nominal Range 500 yards.

Testing was not conducted on 9 Mar 05 due to inclement weather. Diver testing was performed on 10 March 05 as detailed in the test log shown in Table A-3. Four different divers individually listened to transmitted sirens and phrases. Their responses were recorded on a board as shown in Figure A-14.

Table A-3. Underwater loudhailer prototype test log for 10 March 2005.

Run Number	Recorder Take Number	Date	COMEX Time	FINEX Time	Source Transducer Depth (ft)	Receive Hydrophone Depth (ft)	Diver Number	Diver Depth (ft)	Boat Range to Large Sign on Pier (yds)	Boat Latitude (N)	Boat Longitude (W)	CTD Scan	Loudhailer Battery Voltage at COMEX	Wave file used for transmit	Comments / Conditions
TT1	1	3/10/2005	0857	0858	18	15	n/a	n/a	~100	41°31.617	71°19.174	yes	12.7		2.7 kHz tone
TT2	2	3/10/2005	0858	0900	15	18	n/a	n/a	~100				12.7		Tone sequence from day 1/2 tests
104-1	4	3/10/2005	0928	0929	18	15	1	15	105				12.7	siren_phrase1.wav	First Diver
105-1	5	3/10/2005	0933	0934	27	15	1	15	102				12.6	siren_phrase2.wav	
106-1	6	3/10/2005	0936	0937	27	30	1	30	111				12.6	siren_phrase3.wav	
107-1	7	3/10/2005	0937	0938	18	30	1	30	108				12.6	siren_phrase4.wav	
104-2	8	3/10/2005	1000	1001	18	15	2	15	110				12.6	siren_phrase1.wav	Second Diver
105-2	9	3/10/2005	1004	1005	27	15	2	15					12.5	siren_phrase2.wav	
106-2	10	3/10/2005	1006	1007	27	30	2	30					12.5	siren_phrase3.wav	
107-2	11	3/10/2005	1007	1008	18	30	2	30					12.5	siren_phrase4.wav	
112-1	12	3/10/2005	1035	1036	18	15	1	15	400	41°31.578	71°19.365	yes	12.6	new_siren1.wav then beginning of English1.wav	First Diver
113-1	13	3/10/2005	1037	1038	27	15	1	15					12.6	siren_phrase6.wav	
114-1	14	3/10/2005	1039	1040	27	30	1	30	393				12.5	siren_phrase7.wav	
115-1	15	3/10/2005	1041	1042	18	30	1	30					12.4	siren_phrase8.wav	no tone, just voice
112-2	16	3/10/2005	1056	1057	18	15	2	15					12.4	new_siren1.wav then beginning of English1.wav	
113-2	17	3/10/2005	1058	1059	27	15	2	15					12.4	siren_phrase6.wav	
114-2	18	3/10/2005	1100	1101	27	30	2	30					12.4	siren_phrase7.wav	
115-2	19	3/10/2005	1102	1103	18	30	2	30					12.4	siren_phrase8.wav	no tone, just voice, DIVER MISSED BEGINNING WORDS ONLY
116-4	n/a	3/10/2005	1126	1127	18	15	4	15	585			yes	12.4	siren_phrase27.wav	
117-4	21	3/10/2005	1128	1129	27	15	4	15					12.3	siren_phrase28.wav	
118-4	22	3/10/2005	1130	1131	27	30	4	30					12.3	siren_phrase14k.wav	
119-4	23	3/10/2005	1233	1234	18	30	4	30					12.3	siren_phrase13.wav	
116-3	24	3/10/2005	1249	1249	18	15	3	15	580	41°31.551	71°19.478		12.3	siren_phrase27.wav	
117-3	25	3/10/2005	1251	1251	27	15	3	15					12.3	siren_phrase28.wav	
118-3	26	3/10/2005	1252	1252	27	30	3	30	580				12.3	siren_phrase14k.wav	
119-3	27	3/10/2005	1254	1254	18	30	3	30	580				12.3	siren_phrase13.wav	
108-3	28	3/10/2005	1325	1326	18	15	3	15	190	41°31.606	71°19.231	yes	12.3	siren_phrase15.wav	Video taken of diver (ended up blurry unfortunately), No tones for this transmission
109-3	29	3/10/2005	1327	1328	27	15	3	15	190					siren_phrase16.wav	
110-3	30	3/10/2005	1330	1331	27	30	3	30	195					siren_phrase19.wav	
111-3	31	3/10/2005	1331	1332	18	30	3	30						siren_phrase26.wav	
OTS1	32	3/10/2005	1406	1412	15	15	n/a	n/a	110	41°31.624	71°19.177	yes	n/a	tones and messages from March 7 test	Overall test FINEX at 1415

Figure A-14. Diver and response board.

The test phrases are listed below in Table A-4. Not all phrases were used. Several recordings with a female speaker (denoted by “k” in the log) were also used. In general, the results were excellent. The divers detected the presence or absence of a warning tone at all ranges and depths. With one exception (run 155-2, range 400 yds) the divers also correctly heard the transmitted warning message (27 correct out of 28). The one exception occurred when the beginning of a phrase was not preceded by a siren tone and the diver stated that he was breathing during the first and second transmissions. This highlights the importance of a warning tone for voice messages.

Qualitative responses from the divers indicated a “telephone-like” quality to the transmissions. They were able to clearly here both the male and female speakers. Ambient noise from local shipping traffic was quite low due to the time of year and this may have contributed to some of the success.

Table A-4. Test phrases used for diver testing.

1. Stop now. You have entered a restricted area.
2. Attention Diver. Surface immediately.
3. This is the United States Coast Guard.
4. Surface or we will use deadly force.
5. This is your final warning.
6. Surface with your hands in the air
7. This is a restricted zone.
8. I am speaking to you in English.
9. You must surface now.
10. This is the United States Navy.
11. This is a controlled area.
12. Warning. You have entered a restricted area.
13. This is your second warning.
14. Attention Diver. You must surface now.
15. Surface immediately. Surface immediately.
16. Stop. You will be harmed.
17. You are required to surface now.
18. Attention Diver. You must stop.
19. Come up to the surface now.
20. This is your first warning.
21. Raise your right hand now.
22. Come to the surface now.
23. This is a notice to all divers.
24. Attention swimmer. You must stop now.
25. This is a restricted area.
26. Attention Diver: Stop stealing lobsters.

Summary

Initial field testing of a prototype underwater loudhailer was conducted 7-10 Mar 05 at the NUWC Division Newport in conjunction with the RDC. A portable, battery-operated underwater loudhailer was deployed and used to transmit warning tones and messages. The first two days of testing measured the maximum sound pressure level frequency spectrum for different combinations of source depth and receive hydrophone range and depth. In general the range was the dominate factor in determining the sound pressure level. Transmission loss was characterized as between cylindrical and spherical spreading. The propagation conditions were nearly isothermal leading to neither upward- or downward-refracting sound. The prototype loudhailer was able to achieve a maximum SPL of 138-145 dB at a range of 500 yds. The test served as an initial validation of the general loudhailer prototype design including the source transducer array, audio amplifier, control PDA, and software.

During the third day of testing, divers listened to several warning tones and messages and were asked to record what they heard. Out of 28 transmissions, 27 were heard correctly (96% informal intelligibility). The missed transmission was linked to diver breathing and the absence of a warning tone for that particular message. The warning tones and the message repetition were believed to contribute to the high intelligibility. Formal intelligibility testing of the final prototype was conducted in Jun 05 and will be reported separately.

References

Abraham, B., “Underwater Loudhailer Transducer Final Design Report,” TSWG Contract W91CRB-04-C-0057 report dated March 25, 2005, CDRL Data Item A005, Applied Physical Sciences Corp, New London, CT 06320.

Abraham, B., “Underwater Loudhailer Acoustic Requirements Analysis,” TSWG Contract W91CRB-04-C-0057 report dated Nov 4, 2004, CDRL Data Item A005, Applied Physical Sciences Corp, New London, CT 06320.

Rehn, K, Lent, K. and Ruckel, J. “Diver Recall Device Evaluation,” The University of Texas at Austin Applied Research Laboratories report dated March 1, 2004 for the Defense Threat Reduction Agency.

APPENDIX B.

NUWC LOUDHAILER MAR 05 TEST REPORT

Report on the Testing of the Applied Physical Sciences Corporation Prototype Underwater Loudhailer Conducted March 7 – 10, 2005 for the Technical Support Working Group (TSWG) and the Coast Guard Research & Development Center

Roy R. Manstan
Naval Undersea Warfare Center
Engineering & Diving Support Unit
Newport, RI 02841
401-832-7009

November 10, 2005

Report on the Testing of the
Applied Physical Sciences Corporation
Prototype Underwater Loudhailer
Conducted March 7 – 10, 2005

Background

The potential threat from a diver, whether a terrorist or a highly trained military combat swimmer, requires an engagement system that can detect and track an intruder, classify the intruder as "human", and initiate the appropriate response and deterrent. The U.S. Coast Guard (CG) has selected the "Integrated Anti-swimmer System" (IAS) to perform this task.

The IAS currently employs a Kongsberg sonar coupled to the AN/WQX-2 ADCAP processor which, once the intruder is detected and classified, alerts a response boat to intercept and engage the threat. The rules of engagement require that the threat be notified that he has entered a restricted area and provided with additional warnings or instructions prior to deploying any engagement system.

Currently, this notification is provided by a Commercial Off-The-Shelf (COTS) "Diver Recall System" (DRS) that transmits voice messages to divers. The COTS DRS is typically used to provide commercial and recreational divers with information and instructions from surface support personnel. This system employs an omni directional transducer with limited range. In a situation where there is a serious threat and a potential life or death scenario, this limited range and questionable intelligibility poses a serious limitation on a timely deployment of a non-lethal or lethal deterrent.

In order to improve the effective range and intelligibility of the notification, the Technical Support Working Group (TSWG) through the CG pursued the development of an improved Underwater Loudhailer device. Applied Physical Sciences Corp. (APS) was awarded a contract to develop and test a system that would provide a significant improvement over the COTS DRS. Initial tests were performed at the NUWC Dodge Pond Facility. The encouraging results of the Dodge Pond tests supported conducting a second round of prototype tests, but in a typical harbor environment where an Underwater Loudhailer would more likely be deployed.

Test Site

The site selected for the prototype tests was the Coddington Cove and Stillwater Basin area of Narragansett Bay, Rhode Island. The area is bounded by shoreline on the East and South, by a substantial rock breakwater to the North, and faces the East Passage of Narragansett Bay to the West. The test area includes two concrete piers, one of which (Pier 2) supports active CG Cutters and occasional Navy vessels, while the other (Pier 1) provides berthing for the Navy's inactive aircraft carriers Ex-Forrestal and Ex-Saratoga. The waterfront is under Navy control with limited access by other vessels.

A significant amount of the work that NUWC has undertaken in support of Homeland Security and Navy anti-terrorism and force protection technologies has occurred in the Coddington Cove and Stillwater Basin area, primarily near Pier 1. In all cases, NUWC has staged the dry-end "Command & Control" (C&C) on Pier 1 after receiving permission from Navy Inactive Ships, Philadelphia, which controls access to that pier. All diving activities, however, are coordinated with Naval Station Newport, Port Operations located on the adjacent Pier 2.

Test Conditions and Objectives

The APS Underwater Loudhailer prototype tests were conducted the week of 7 March 2005. There were two primary objectives. First, to measure the acoustic propagation characteristics of the Loudhailer in a harbor environment. The second was to obtain initial indications of the intelligibility of the APS system at specific ranges and depths. In addition to the acoustic performance, the prototype tests were also intended to provide design feedback for the dry-end control system. This information was incorporated into what would evolve from a prototype into the APS Enhanced Loudhailer (*e*LOUD) system that became the subject of the subsequent June field tests.

In March, the water temperature in the test area varies from the low to mid 30's (°F). The temperature profile is fairly uniform with depth as is the sound velocity profile (SVP).

Human Subjects Testing

Although the RDC provided overall test direction, NUWC was responsible for conducting the March tests and all related diving operations. Because the testing involved obtaining the response of divers to transmitted acoustic tones and voice messages, the use of divers falls under guidelines for human subjects testing. A test protocol was submitted to the NUWC Institutional Review Board (IRB), which has human subjects testing oversight and is responsible for approval of the protocol.

The test protocol, NUWC.2004.0003 "Evaluation of Underwater Loudhailer for Transmitting Voice Messages to Divers", is provided as Appendix B(1). Included are the Investigator Assurance form, the Informed Consent form, and the IRB approval letter. The protocol was originally submitted on 13 Dec 2004 with a minor modification submitted on 13 Jan 2005.

The subsequent field testing in June of the APS *e*LOUD™ Underwater Loudhailer was the responsibility of the Naval Submarine Medical Research Lab (NSMRL). Even though the June testing procedures were similar to the March prototype tests, it was necessary for NSMRL to submit its own test protocol to their agency's IRB for approval.

It is a requirement that divers who volunteer to participate in any Navy protocol, including NUWC and NSMRL, be Navy qualified divers. On rare occasions, it is possible to waive this requirement in order to obtain unique capabilities not available within the community of Navy qualified divers. There was some discussion of this possibility in order to include female divers and divers with foreign language capabilities (e.g.,Spanish, Arabic, Chinese). It was decided, however, that this was beyond the scope of the *e*LOUD™ field tests, and that only English word

lists and messages would be transmitted. It would be advisable to consider this option for future evaluations of the *e*LOUD™ loudhailer.

The test subjects participating in the March prototype tests were drawn exclusively from the NUWC Engineering & Diving Support Unit (EDSU). The divers were required to wear identical "head gear" (i.e., neoprene cold water wetsuit hoods) in order to maintain a consistent cover over each subject's ears. They were, however, allowed to wear drysuits for their overall thermal protection due to the very low water temperatures.

The test subjects who participated in the June field tests were selected from NUWC, NSMRL, and CG Maritime Safety & Security Teams (MSST), all having a minimum of Navy SCUBA qualification.

Environmental Requirements

Environmental approvals must be obtained for testing any underwater acoustic device. Because NUWC was responsible for conducting the March prototype tests, funded by the TSWG, it was necessary to solicit approval from the NUWC Environmental Review Board (ERB). The test conditions and objectives were submitted to the ERB on 17 Dec 2004. Approval was granted via a "Memorandum for the Record" on 11 Jan 2005. This document, along with a modification memo, is provided as Appendix B(2). The approval memorandum outlines the test conditions and states: "This project was determined not to meet the requirements for a major federal action requiring further review under the National Environmental Policy Act of 1969." The implications here are that neither an Environmental Assessment (EA) nor an Environmental Impact Statement (EIS) were required. In addition, the approval was granted for one year and covered both the March and June testing. It would be anticipated that obtaining future approvals beyond the one year lapse date would be straight forward.

If accepted as a component of the IAS (replacing the COTS DRS), the *e*LOUD™ acoustic propagation measurements will provide supporting data that can be incorporated into future environmental assessments of the overall IAS.

Description of the Prototype Testing

A detailed account of the March test results has been documented in the "Underwater Loudhailer Prototype Test Report,", September 20, 2005, by Bruce Abraham, Ph.D., Applied Physical Sciences Corp., 2 State Street, Suite 300, New London, CT 06320. The subsequent June testing has also been reported by Bruce Abraham in the "Enhanced Underwater Loudhailer (*e*LOUD) Field Test and Specifications Report,", October 17, 2005.

The following is an overview and summary of the NUWC operations during the March prototype tests.

All of the March data acquisition and diving operations were conducted on board the NUWC "WB-30". This work boat provided a closed cabin for personnel to record the receive

hydrophone data and to record the divers' responses. It also provided an area to keep the test subjects warm during the operation.

The acoustic propagation tests occurred on March 7 and 8, 2005. There was no diving during this phase of the data acquisition. In any acoustic test involving human subjects it is essential to determine the sound levels that the divers will experience, and to ensure that these levels fall within the permissible exposure guidelines. The Navy's guidelines have been established by NSMRL, and were followed for both the March and June tests.

Test personnel on the transmit end (Pier 1) included individuals from RDC (test direction), from NUWC (test coordination), and from APS (system operation). The receive hydrophone data acquisition was performed by APS with assistance from NUWC. Receive hydrophone data was also collected by APS during the diving operations. All diving, however, was the responsibility of NUWC. Sound velocity profile (SVP) data was collected at various times during the tests by NUWC, and passed to APS to aid in their acoustic propagation analysis.

Diving operations occurred on 10 March 2005 and were conducted from the aft deck of the WB-30. The test subjects were provided with a plexiglass slate with provisions for recording their responses with a grease pencil. After each diver completed a series of test events, their recorded responses were passed to topside personnel who transcribed the responses to data sheets, then cleaned and passed the slate to the next test subject.

Tones and messages were transmitted to a test subject positioned at a depth of 15 ft with the Loudhailer set first at a depth of 18 ft and then at 27 ft. The subject was then instructed to move to a depth of 30 ft with the Loudhailer again operating at 18 ft and 27 ft. This procedure was repeated for multiple test subjects at several ranges. Details as to the specific locations where the data was collected within Coddington Cove and Stillwater Basin, along with the tabulated results, are found in the "Underwater Loudhailer Prototype Test Report,", Oct 17 2005, by Bruce Abraham referenced above.

The acoustic propagation data from the 7th and 8th indicated that the range to begin human testing would be 100 yards. If the responses were positive (i.e. good intelligibility) the range would be extended to 400 yards, and then to 600 yards. Other ranges and bearings would be tried if time permitted.

The WB-30 was anchored such that the diver would be deployed at approximately the ranges described above. Because the WB-30 used a single anchor point, there was some movement as the boat shifted due to wind and current. The position, however, was monitored with a laser rangefinder and the actual range from the test subject to the pier was recorded. Thus, the "100 yard" test actually varied from 102 yards to 111 yards; the "400 yard" test ranged from 385 yards to 400 yards; and the "600 yard" test was actually 580 yards to 585 yards. A final test set run at "200 yards" was 190 yards to 195 yards.

Summary

The acoustic propagation conditions in March, with the relatively uniform temperature profile, were optimal. Of the total of 28 test events, the divers were able to record all but a portion of

one message. Of particular note was that the test subjects successfully recorded the transmitted messages out to 585 yards. The system performance was encouraging and with some adjustments to the system, it was recommended that the Loudhailer be subjected to a follow-on evaluation of the final prototype. This next series of tests (June 2005) also viewed the acoustic propagation, but concentrated on the evaluation of the system intelligibility. The June tests were conducted by NSMRL, where the responses included a statistical sampling of divers from NSMRL, the CG, and the NUWC EDSU.

NSMRL visited the site during the diving portion of the March prototype tests. This visit provided both the NSMRL Principal Investigator (Dr. Ed Cudahy) and Master Diver (Rick Donlon) with a preliminary view of the site conditions that would be incorporated into the NSMRL protocol for the June intelligibility tests.

Overall responsibility for NUWC participation in both the March and June tests was Roy Manstan. Jack Hughes, NUWC Diving Officer, was responsible for conducting the March tests and coordinating the participation of the three agencies involved with the June tests. Sam Carroll assisted with the data acquisition during the March tests and with the *e*LOUD™ transmit system operation in June. Mr. Carroll also provided comments regarding the operation of the *e*LOUD™ system during the June field tests. These comments are provided in Appendix B(3). All three individuals are familiar with the performance of the *e*LOUD™ loudhailer and can be contacted through the EDSU at (401) 832-7009.

The June *e*LOUD™ Loudhailer field tests were conducted by NSMRL. NUWC provided logistical support throughout the test period, assisted with the dry end system operation, and provided test subjects. A final report that addresses the acoustic propagation and the evaluation of system intelligibility will be provided by NSMRL.

Future testing may include the use of female test subjects as well as foreign language speaking divers. As discussed earlier, if these divers are not U.S. Navy qualified divers there will be a requirement to obtain waivers from NAVSEA for them to participate.

Appendix B(1)

NUWC Institutional Review Board
Documentation for Human Subjects Testing

PROTECTION OF HUMAN SUBJECTS
RESEARCH PROTOCOL SUBMISSION FORM

(SUBMISSION DATE: 22 November 2005

PROTOCOL/RESEARCH TITLE: Evaluation of Underwater Loudhailer for Transmitting Voice Messages to Divers

PRINCIPAL INVESTIGATOR (full name): Samuel Carroll

CODE: 8134 **PHONE**: (401) 832-6676 **FAX: (**401) 832-4657

BLDG/ROOM: Bldg 148 Rm 211 **E-MAIL ADDRESS:** **CarrollSV@npt.nuwc.navy.mil**

JOINT/COOPERATIVE RESEARCH:
ORG NAME/COMPANY NAME: Coast Guard Research & Development CenterPOC: Ric Walker
TEL. #: 860-441-2728 BUS ADDRESS: Groton CT

AGREEMENTS/CONTRACTS
(CRADA, Cooperative Research, etc.): MOU Dec 2002 between NUWC and Coast Guard R&D Center, Underwater Port Security Program.

TYPE OF HUMAN SUBJECTS RESEARCH TO BE DONE
The research is designed to determine intelligibility performance of an underwater speaker (Loudhailer) at various ranges.

START DATE AND DURATION OF RESEARCH EFFORT:
Initial test scheduled for February 2005. Subsequent testing under this protocol will occur.

PROTOCOL FIRST SUBMISSION (y/n) N

AMEND TO EXISTING PROTOCOL (y/n) Yes, Change of principal investigator from Roy Manstan (code 1515) to Samuel Carroll (code 8134).

SECTION 1 - BRIEF DESCRIPTION:

There has recently been a great deal of interest in the ability to detect and classify a swimmer or diver in the vicinity of a High Value Asset, be it a ship or the waterfront infrastructure itself. Experimental as well as COTS active acoustic systems are being investigated that purport to be able to detect an intruder. Once the intruder is detected, it is necessary to notify the individual that he or she must exit the water. The underwater loudhailer which is the subject of this

protocol is designed to provide that notification. The tests will place test subjects at various ranges from the loudhailer, and they will report on the performance of the voice transmissions. Initial tests will provide qualitative performance evaluations. Subsequent tests will incorporate standard word lists and phrases. Multiple languages will be used pending availability of qualified divers with specific language capabilities.

SECTION 2 - BENEFITS FROM RESEARCH:

NUWC has sponsored a Homeland Security Initiative, under the direction of Jim Pollock. The MOU between NUWC and RDC facilitates collaborative RDT&E. The CG has a distinct underwater port security mission that requires adaptation of acoustic technologies to this mission. Swimmer engagement using acoustic systems fits both the CG mission as well as that of NUWC. The data from tests of an improved underwater loudhailer will benefit both the CG and the Navy. Current off the shelf systems do not have the required range and new systems have been proposed to improve range and intelligibility.

SECTION 3 – PROCEDURES: The experimental design and brief description of the procedures.

All test subjects will be Navy qualified divers, primarily drawn from the NUWC Engineering & Diving Support Unit (EDSU) and from CG (Navy qualified) dive teams. Testing will be conducted at various locations, and could include Narragansett Bay, the Dodge Pond Facility, and AUTEC. Selection of specific locations has yet to be determined, and will be based on port and harbor conditions that might be encountered if the loudhailer were to be deployed in an operational scenario. A variety of conditions are being considered due to their effect on sound wave propagation including various sound velocity profiles, bottom type and topography, and ambient sound levels. The testing will require a diver to position himself at specified locations (range and depth) in the water column. The diver will be instructed to remain stationary by holding onto a descent line anchored on the bottom and with a sub-surface float to keep the line taught. The subject will face the acoustic source and breathe at a normal rate. The standard operating procedure for loudhailer use will include two or more warning tones followed by the voice message. Because the noise from a SCUBA breathing cycle (inhale/exhale) can interfere with the ability of the diver to hear all the words of a voice message, the message will be repeated. The diver will record the words heard and provide a qualitative assessment of the system performance. Divers will be monitored prior to and at the end of each trial and asked if they have experienced any adverse reactions to the test. Prior to each trial the diver will also be asked if he would like to continue or to be relieved by an alternate diver in order to account for the effects of water temperature and fatigue. This is included as part of any pre-dive brief and as such is standard Navy diving protocol.

SECTION 4 - RISKS: A discussion of all significant risks and the measures used to minimize those risks, as well as procedures to minimize the effect of emergencies. This discussion shall be in such detail as to facilitate a thorough risk/benefit analysis.

Because all test subjects are Navy trained divers, the diving equipment used during testing as well as the in-water operations are considered routine and should not be a consideration among risk factors associated with the test. The Loudhailer will transmit between 800 Hz and 5000 Hz

which will provide sufficient bandwidth for clear speech detection. Research conducted at NSMRL in Groton, CT has established guidelines for safe diving distances from transmitting sonars (NSMRL POC is Dr. Ed Cudahy at (860) 694-3391). The research, using test subjects, has indicated that at 1000 Hz, aversion reactions were recorded for some (not all) of the test subjects when the Sound Pressure Level (SPL) at the diver exceeded 155 dB re 1 micro Pascal. It should be understood that there was no physiological damage, only aversion to the sound. The resulting NSMRL guidelines for 1000 Hz specify that a bareheaded (no wet suit hood) diver will have a maximum continuous exposure duration of 28 seconds at 155 dB with a maximum duty cycle of 50%, and a maximum continuous exposure over a 24 hour period of 8 hours at 150 dB. When wearing a hood, the SPL exposure limits increase by 10 dB (i.e. 165 dB for 28 sec) up to a depth of 20 ft, and by 5 dB (i.e. 160 dB for 28 sec) from 20 ft to 50 ft. This is due to the protection afforded the ears by the neoprene hood in shallow water, but which is reduced as the neoprene compresses with depth providing no additional ear protection below 50 ft. It must be emphasized that these exposure limits are not indicators of potential physiological damage, but are based on aversion reactions in the NSMRL test subjects. The researchers at NSMRL have provided further guidance at higher frequencies. These guidelines for 3500 Hz specify that a bareheaded diver is allowed a maximum continuous exposure duration of 28 seconds at 165 dB with a maximum duty cycle of 50%, and a maximum continuous exposure over a 24 hour period of 8 hours at 160 dB. When wearing a hood, the SPL exposures increase by 10 dB up to a depth of 20 ft (i.e. 175 dB for 28 sec), and by 5 dB (i.e. 170 dB for 28 sec) from 20 ft to 50 ft. The guidelines for 7000 Hz further increase these allowable SPL exposures by 10 dB. Acoustic propagation tests of the Loudhailer were performed at the NUWC Dodge Pond Facility. Measured transmission loss as a function of range closely followed the expected spherical spreading, i.e. a 20 dB reduction at 10 yds and a 40 dB reduction at 100 yds. All tests of the Loudhailer will typically be restricted to a source level of 180 dB; thus the SPL will be 160 dB at 10 yds and 140 dB at 100 yds. Based on the NSMRL guidelines, a hooded diver could operate at 10 yds to a depth of 50 ft. A bareheaded diver would require a range of 20 yds which provides approximately 26 dB transmission loss (TL) from the 180 dB source level to get below a SPL of 155 dB at the diver. Marker buoys will be placed at ranges specified by the test plan. No testing will occur with divers closer than 50 yds which provides an additional safety margin over the range limits indicated above. Prior to any testing using divers, the SPL will be measured at each test location to verify the SPL that the divers will experience. It is anticipated that the maximum range will be 500 yds where the SPL should be approximately 126 dB. At this extended range, the source level may be increased to 190 dB if the diver has difficulty hearing the voice transmissions at 180 dB. Because of the controls that will be in place over the location of the test subjects it is my opinion that the measurements described here are “minimal risk” as defined in NUWCDIVNPTINST 3900.5A.

SECTION 5 – SUBJECTS: The total number of subjects required, with an indication of pertinent selection criteria such as age, sex, and their special qualifications.

The pool of potential test subjects will come primarily from the NUWC Engineering & Diving Support Unit (EDSU), and from the CG Marine Safety and Security Teams (MSST). The primary requirement, however, is that the test subject be a qualified Navy diver.

5a – Necessity for Human Subjects: Justification to show that use of human subjects is necessary and that sufficient information could not be gained by animal testing or other research not involving the use of human subjects.

The purpose of the test is specifically related the ability to transmit voice messages to human divers using active acoustic systems and, as such, human subjects are required.

5c – Sample Size: A determination of the adequacy of the proposed sample size. (An explanation must be provided if sample size calculation is not appropriate).

Human subjects will be wearing an assortment of diving equipment. Initial tests will only require a small selection of test subjects and will only provide qualitative feedback as to system performance. The tests will include standard word lists and phrases transmitted to the divers. The number of test subjects will likely not exceed six for each set of measurements. The results of these tests are qualitative evaluations by the divers that will be used to feed back into the system design and as such the number of divers selected is not based on a statistical sampling of test subjects.

5d – Cessation: List criteria for cessation of a subject's ongoing exposure.

Divers will be monitored prior to and at the end of each measurement and asked if they have experienced any adverse reactions to the test. Prior to each trial the diver will also be asked if they would like to continue or to be relieved by an alternate diver with specific emphasis on their participation in the test, as well as to account for the effects of water temperature and fatigue. This is included as part of any pre-dive brief and as such is standard Navy diving protocol.

5e – Elimination/Disqualification: List the criteria for the elimination or disqualification of a subject from the project.

All participation in this testing is voluntary, and the subject may withdraw at any time and for any reason. In addition, the subject must be physically fit to perform the dive. Thus the diver's condition is assessed prior to each dive, and the dive supervisor has the authority to disqualify a participating diver for reasons such as the individual is sick and can't equalize the pressure in his ears.

5f – Medical Monitor: List the name and phone number of the proposed medical monitor(s), if appropriate.

Christine Fisher RN, NUWCDIVNPT, 401-832-5892

5g – Privacy of Human Subjects: A description of how anonymity will be maintained for any identifiable data collected or used.

The measurement data will be based on the equipment used and not on the presence of a specific test subject. The diving supervisor, however, is required to maintain a dive log that describes the diving operation (depth, time, etc). There is no requirement to merge the dive log with the data, so that there will be no correlation between the particular test run and the individual test subject who performed the dive.

5h – Informed Consent: Provide a sample of the informed consent document each human subject must sign. Form should include name of the principle investigator, purpose of experiment, use of the data, risk, if any, and an indication that subjects are participating voluntarily and may withdraw at any time.

See attached consent form.

ADDITIONAL INFO (optional): Any additional information not asked in the above that you feel is important to mention.

The pre-Dive checklist as well as the “Smooth Copy” of the dive log which identifies dive conditions and individual divers will be provided to the IRB for documentation.

BACKGROUND

The threat from a terrorist diver or combat swimmer is real. The Navy has always had an underwater force protection requirement, but the threat to Homeland Security has vastly increased the waterfront subjected to a potential terrorist. To react to this threat, a variety of systems have been developed in the commercial world to detect, classify, and track a diver. An initial response to a diver who may or may not be a threat requires that the diver be notified that he/she has been detected, is in a restricted security zone, and must surface and leave the area. Because the CG is responsible for U.S. coastal waters where there are many commercial and recreational divers, there is definite requirement for notifying a detected diver prior to any intervention. The CG, therefore, has initiated a program to test potential swimmer engagement technologies that include diver notification via what is referred to as an underwater “loudhailer”. This technology is also of interest to the Navy’s Force Protection mission.

INFORMED CONSENT DOCUMENT

HRPP#: NUWC.2004.0003.

Title of Study: Evaluation of Underwater Loudhailer for Transmitting Voice Messages to Divers

Authority: This minimal risk human subjects research is conducted under the Naval Undersea Warfare Center's Institutional Assurance issued by the Department of the Navy, Bureau of Medicine and Surgery dated 1-May-03. All human subjects testing will be in accordance with the following instructions and government regulations: 32 C.F.R. § 219; DoD directive 3216.2; SECVAV 3900.39C; BUMEDINST 3900.6B and; NUWC instruction 3900.5A. These instructions require that the researchers obtain your written, voluntary consent before you may participate in the study, experiment, or test. You are not required to complete this form, you are not required to provide the requested information; however, if you decide not to complete the form or not to provide the requested information, the researchers cannot allow you to participate in the research study.

Purpose of study: The objective of this study is to obtain performance evaluations of an underwater loudhailer. The Loudhailer is designed to be used to notify a diver that he/she has entered a restricted security zone and must surface and depart the area.

Description of the procedures to be followed: All test subjects will be Navy qualified divers, primarily drawn from the NUWC Engineering & Diving Support Unit (EDSU) and from CG (Navy qualified) dive teams. Testing will be conducted at various locations, and could include Narragansett Bay, the Dodge Pond Facility, and AUTEC. Selection of the specific location has yet to be determined, and will be based on port and harbor conditions that might be encountered if the loudhailer were to be deployed in an operational scenario. A variety of conditions are being considered due to their effect on sound wave propagation including various sound velocity profiles, bottom type and topography, and ambient sound levels. The testing will require a diver to position himself at specified locations (range and depth) in the water column. The diver will be instructed to remain stationary by holding onto a descent line anchored on the bottom and with a sub-surface float to keep the line taught. The subject will face the acoustic source and breathe at a normal rate. The standard operating procedure for loudhailer use will include two or more warning tones followed by the voice message. Because the noise from a SCUBA breathing cycle (inhale/exhale) can interfere with the ability of the diver to hear all the words of a voice message, the message will be repeated. The diver will record the words heard and provide a qualitative assessment of the system performance. Divers will be monitored prior to and at the end of each trial and asked if they have experienced any adverse reactions to the test. Prior to each trial the diver will also be asked if he would like to continue or to be relieved by an alternate diver in order to account for the effects of water temperature and fatigue. This is included as part of any pre-dive brief and as such is standard Navy diving protocol.

Are any of the procedures experimental? If so what are they?: All diving will follow standard navy diving procedures. None of the procedures associated with the system tests involving human subjects are considered experimental.

Location of study: Testing will be conducted in the Stillwater Basin area of Narragansett Bay.

Risks to subject: Because all test subjects are Navy trained divers, the diving equipment used during testing as well as the in-water operations are considered routine and should not be a consideration among risk factors associated with the test. The Loudhailer will transmit between 800 Hz and 5000 Hz which will provide sufficient bandwidth for clear speech detection. Research conducted at the NSMRL in Groton, CT has established guidelines for safe diving distances from transmitting sonars. The research, using test subjects, has indicated that at 1000 Hz, aversion reactions were recorded for some (not all) of the test subjects when the Sound Pressure Level (SPL) at the diver exceeded 155 dB re 1 micropascal. It should be understood that there was no physiological damage, only aversion to the sound. The resulting NSMRL guidelines for 1000 Hz specify that a bareheaded (no wet suit hood) diver will have a maximum continuous exposure duration of 28 seconds at 155 dB with a maximum duty cycle of 50%, and a maximum continuous exposure over a 24 hour period of 8 hours at 150 dB. When wearing a hood, the SPL exposure limits increase by 10 dB (i.e. 165 dB for 28 sec) up to a depth of 20 ft, and by 5 dB (i.e. 160 dB for 28 sec) from 20 ft to 50 ft. This is due to the protection afforded the ears by the neoprene hood in shallow water, but which is reduced as the neoprene compresses with depth providing no additional ear protection below 50 ft. It must be emphasized that these exposure limits are not indicators of potential physiological damage, but are based on aversion reactions in the NSMRL test subjects. The researchers at NSMRL have provided further guidance at higher frequencies. These guidelines for 3500 Hz specify that a bareheaded diver is allowed a maximum continuous exposure duration of 28 seconds at 165 dB with a maximum duty cycle of 50%, and a maximum continuous exposure over a 24 hour period of 8 hours at 160 dB. When wearing a hood, the SPL exposures increase by 10 dB up to a depth of 20 ft (i.e. 175 dB for 28 sec), and by 5 dB (i.e. 170 dB for 28 sec) from 20 ft to 50 ft. The guidelines for 7000 Hz further increase these allowable SPL exposures by 10 dB. Acoustic propagation tests of the Loudhailer were performed at the NUWC Dodge Pond Facility. Measured transmission loss as a function of range closely followed the expected spherical spreading, i.e. a 20 dB reduction at 10 yds and a 40 dB reduction at 100 yds. All tests of the Loudhailer will typically be restricted to a source level of 180 dB; thus the SPL will be 160 dB at 10 yds and 140 dB at 100 yds. Based on the NSMRL guidelines, a hooded diver could operate at 10 yds to a depth of 50 ft. A bareheaded diver would require a range of 20 yds which provides approximately 26 dB transmission loss (TL) from the 180 dB source level to get below a SPL of 155 dB at the diver. Marker buoys will be placed at ranges specified by the test plan. No testing will occur with divers closer than 50 yds which provides an additional safety margin over the range limits indicated above. Prior to any testing using divers, the SPL will be measured at each test location to verify the SPL that the divers will experience. It is anticipated that the maximum range will be 500 yds where the SPL should be approximately 126 dB. At this extended range, the source level may be increased to 190 dB if the diver has difficulty hearing the voice transmissions at 180 dB. Because of the controls that will be in place over the location of the test subjects it is my opinion that the measurements described here are “minimal risk” as defined in NUWCDIVNPTINST 3900.5A.

Benefits: NUWC has sponsored a Homeland Security Initiative, under the direction of Jim Pollock. The MOU between NUWC and the RDC facilitates collaborative RDT&E. The CG has a distinct underwater port security mission that requires adaptation of acoustic technologies to this mission. Swimmer engagement using acoustic systems fits both the CG mission as well as that of NUWC. The data from tests of an improved underwater loudhailer will benefit both

the CG and the Navy. Current off the shelf systems do not have the required range and new systems have been proposed to improve range and intelligibility.

Use and Confidentiality of Data: The data collected will be analyzed and the results may be published. The data and all related information will be held in confidence and will not be associated with your name or identity outside the context of the study or in any published results. The data and related information will remain confidential even after the study has ended. The data and documents will be stored at the NUWC Division Newport, RI. Only researchers associated with this study will have access to the information except the possibility that government agencies may inspect the records

Voluntary participation: Participation in this research is voluntary, and refusal to participate involves no penalty or loss of benefits to which you are otherwise entitled, and you may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled.

Point of contact: Roy Manstan, NUWC Engineering & Diving Support Unit Program Manager, Code 72D, 401-832-7009, manstanrr@npt.nuwc.navy.mil

For Further Information: For specific questions about the nature of the research, the POC above should be contacted. For information as to your rights as a subject or in the case of a research-related injury contact the Chairman of the Institutional Review Board for Human Subjects Testing at NUWC in Newport, RI: Ann Silva email: SilvaAH@npt.nuwc.navy.mil or voice: (401) 832-3355.

<u>You will be given a copy of this form for your records.</u>

Statement of consent:

Please confirm that:

1) you have read the above information;
2) you have had the opportunity to ask questions, and they have been answered;
3) you understand that you do not have to fill out this form;
4) you do not have to participate in this research and;
5) you voluntarily consent to participate in the research.

Signature of Volunteer	Date
Signature of Principal Investigator	Date
Signature of Witness	Date

DEPARTMENT OF THE NAVY
NAVAL UNDERSEA WARFARE CENTER DIVISION
1176 HOWELL STREET
NEWPORT RI 02841-1708

IN REPLY REFER TO:
Ser 5221/1
2 Feb 05

From: A. Silva, Chairman, Protection of Human Subjects Institutional Review Board
To: CAPT John C. Mickey, Approving Official

Subj: RECOMMEND APPROVAL OF HUMAN SUBJECTS TESTING PROTOCOL

Encl: (1) Protocol Review Package entitled, "Evaluation of Underwater Loudhailer for Transmitting Voice Messages to Divers", NUWC ID # NUWC.2004.0003.

1. The Human Subjects Institutional Review Board (IRB), as defined in NUWCDIVNPT Instruction 3900.5A, met on 20 December 2004 to consider a human subject testing protocol. The protocol was entitled, "Evaluation of Underwater Loudhailer for Transmitting Voice Messages to Divers". The Principal Investigator is Mr. Roy Manstan. The IRB agreed the protocol was minimal risk and approved the testing.

2. The IRB did request that Mr. Manstan contact the Navy Environmental Protection Agency (NEPA) to insure that they had no problem with the protocol. Mr. Manstan was also asked to add Point of Contact (POC) information from Naval Submarine Medical Research Lab (NSMRL) to the protocol. Mr. Manstan complied with both requests.

3. Enclosure (1) is forwarded to you for your approval.

✓ Approved ____ Disapproved

____ Approved with additional safeguards or modifications listed below:

Signed:
CAPT JOHN C. MICKEY

3. If you have any questions or need further information in regard to this protocol review package, please contact the undersigned at extension 23355.

Ann H. Silva
ANN H. SILVA
CHAIR, INSTITUTIONAL REVIEW BOARD

INVESTIGATOR'S ASSURANCE

I certify that, to the best of my knowledge and belief, the information provided in this protocol entitled "**Evaluation of Underwater Loudhailer for Transmitting Voice Messages to Divers**" is complete and correct.

I understand that as Principal Investigator, I have ultimate responsibility for the conduct and ethical performance of the study, the protection of the rights and welfare of human subjects, and strict adherence to any stipulations imposed by the Naval Undersea Warfare Center (NUWC) Institutional Review Board (IRB).

I have (1) read, (2) understood, and (3) will abide by the provisions of the following regulations provided by the NUWC IRB:

- 32 Code of Federal Regulations Part 219 (Protection of Human Subjects) [provided as enclosure 1], and
- Naval Undersea Warfare Center Division Newport Instruction 3900.5A [provided as enclosure 2].

I agree to comply with these regulations regarding the protection of human subjects in this study, including, but not limited to, the following:

- Performing the project by qualified personnel according to the approved protocol or test plan.
- Implementing no changes to the application, approved protocol or test plan, and consent form without prior HSPC approval.
- Obtaining informed consent from the human subjects and using only the most recently approved consent form for this study.
- Immediately suspending any test that endangers the health or safety of a human subject, even if an incident occurs only momentarily, except when continuation is necessary to eliminate immediate hazards to the subject.
- Promptly reporting to the HSPC any adverse event that endangers the health or safety of the human subject.

If I will be unavailable to personally direct this study, I will arrange for an on-site co-investigator who has signed a Co-Investigator's Assurance to assume direct responsibility in my absence. Either this person is named as a co-investigator in this application and the person's assurance is attached, or I will advise the NUWC IRB Chair in writing in advance of such arrangements and will provide the assurance at that time.

____________________________________ ________________

Principal Investigator Date

____________________________________ ________________

Co-investigator Date

Appendix B(2)

NUWC Environmental Review Board
Documentation for Acoustic Testing of Underwater Loudhailer

DEPARTMENT OF THE NAVY
NAVAL UNDERSEA WARFARE CENTER DIVISION
1176 HOWELL STREET
NEWPORT RI 02841-1708

IN REPLY REFER TO:
551:CGT:kw
Ser 5551/2
11 Jan 05

MEMORANDUM FOR THE RECORD

From: Code 55

Subj EVALUATION OF UNDERWATER LOUDHAILER FOR TRANSMITTING VOICE MESSAGES TO DIVERS

Ref: (a) ERB Mtg of 17 Dec 04
(b) NUWCDIVNPT memo Ser 3551/57 of 2 Jun 03
(c) OPNAVINST 5090.1B

1. The Naval Undersea Warfare Center Division, Newport proposes to support Coast Guard testing of an underwater loudhailer for transmitting voice messages to divers in the area of Piers 1 and 2 at Naval Station Newport. As was discussed during reference (a), a loudhailer is being considered by the Coast Guard as a component of their swimmer engagement system. Tests of another component, diver detection system, were reviewed for environmental impact in reference (b).

2. For these tests, divers will be deployed to evaluate the intelligibility of the loudhailer at specified ranges from the source under different seasonal conditions. The test series are expected to cover six days, the first two of which would be to determine the acoustic propagation characteristics in the test area. Testing will occur during daylight hours and is expected to consist of two to three hour sessions in both the morning and afternoon. Tests may occur year-round in order to evaluate the effects of different diver dress (e.g. hooded drysuit, unhooded wetsuit) and environmental conditions (e.g. sound velocity profile, ambient noise) on the ability to hear the transmitted voice.

3. The source level of the transmissions will be 180 dB re 1μPa at 1m with limited testing at 190 dB and the frequency range will be between 300 and 5000 Hz. The beam width will be 25° vertically and 360° horizontally. The transmissions will consist of 1 KHz tones, acoustic "chirps" (linear sweeps between 300 and 5000 Hz), voice messages, and word lists. A typical transmission to the diver will consist of a two second tone at 1 KHz, a one second delay, another two second tone, a one second delay, followed by a voice message up to nine seconds. There would then be another approximate 10 second delay before transmitting the next voice message. There may be 10 of these transmissions for a

particular data set (i.e. different word list or different message) at which time the diver will reposition himself for the next data set.

4. The majority of the test time will involve placement of the divers and retrieving their response information before moving to the next data set. Thus, there will be significant intervals between data sets, and it is anticipated that the total time during which the transmissions will occur (cumulative effect) may only be about 20% of the total.

5. The issue of diver safety was discussed during reference (a), and it was stated that this was being addressed by the Institutional Review Board. Performing the test within the restricted area of Coddington Cove eliminates the potential for impact to divers not involved in the testing. The only other issue noted during reference (a) was the potential presence of harbor seals (*Phoca vitulina*) in the test area from November to May. Due to the characteristics of the system and the test process described above, there is no potential to adversely affect the hearing of harbor seals. Coddington Cove is not known to be an area frequently used by seals, and the presence of boats and divers would not be expected to attract seals. Loudhailer testing is not expected to cause changes in normal seal behavior.

6. This project was reviewed for potential environmental impacts in accordance with reference (c). This project was determined not to meet requirements for a major federal action requiring further review under the National Environmental Policy Act of 1969.

7. If there are any questions, or if additional information is needed, please call Chris Tompsett at (401) 832-5845.

Daniel J. Burke

DANIEL J. BURKE
Chairman,
Environmental Review Board

Copy to:
1551 (R. Manstan, S. McCarthy)

DEPARTMENT OF THE NAVY
NAVAL UNDERSEA WARFARE CENTER DIVISION
1176 HOWELL STREET
NEWPORT RI 02841-1708

IN REPLY REFER TO:
551:EMP:kc
Ser 5551/7
4 Feb 05

MEMORANDUM FOR THE RECORD

From: Code 55

Subj: MODIFICATION OF ACTION PROPONENT FOR EVALUATION OF UNDERWATER LOUDHAILER FOR TRANSMITTING VOICE MESSAGES TO DIVERS

Ref: (a) NUWCDIVNPT memo Ser 5551/2 of 11 Jan 05

1. Reference (a) incorrectly stated the action proponent. The correct action proponent is the Counter Terrorism Technology Support Office.

2. All other findings remain the same as found in reference (a).

3. If there are any questions, or if additional information is needed, please call Ellen Peoples at (401) 832-5882.

Dan Burke
DANIEL J. BURKE
Chairman,
Environmental Review Board

Copy to:
1551 (R. Manstan, S. McCarthy)

Appendix B(3)

Comments Regarding the *e*LOUD™ Loudhailer Operation During the June 05 Field Testing

e-Loud Evaluation Comments provided by NUWC

The *e*Loud™ system was qualitatively assessed over a seven-day period on the Narragansett Bay from June 13th to June 22nd. In an effort to be concise, the assessment is ordered by bullet points and short sentences. Below (+) means a positive feature, (-) means a negative feature followed by a recommendation (usually) and (?) means was not observed. The italics are used to emphasize a specific area, i.e. *Safety*. The e-loud system assessment is segmented into five parts, Packaging, Wet-End, Deck Unit, Connectors/Jacks and Power/Internal.

Packaging

- (+) The Deck Unit and Wet-End are easily stored in Pelican cases. The cases are rugged and robust. One person can easily carry the entire system.
- (-) The weights needed for small boat deployment must be carried separately.
- (+) The yellow X-ducer cable is easy to see and differentiate from rope.

Wet-End

- (+) X-ducers are lightweight and easily deployed.
- (+) Nylon straps and D-rings on X-ducers are easily replaced.
- (-) The rope and signal wire are flexible and light (better than a rigid pole). However, the rope and wire can tangle when retrieved or when hanging below a small boat. Each X-ducer disc has a large surface area and is susceptible to (current / boat) movement and may not hang vertical. This was evident when maneuvering a small boat at low speed. The signal-wire and rope became entangled in the propeller. The rope and wire could be wrapped together for 5-10 feet from top X-ducer (with tie-wraps etc.). More than 10 lbs of ballast is needed when deployed from a small boat in a current.

Deck Unit

- (-) The current configuration does not appear to be splash proof.
- (-) Labels on lighted Power/Transmit buttons are not clear in direct sun.
- (-) IPAQ cover is tinted and should be clear.
- (-) IPAQ display is not back lit and hard to see unless in direct light. This also makes the unit susceptible to glare when viewing at angles other than directly over top of the display.

- (-) IPAQ monitor is small. A *larger* laptop monitor would make operation much easier.
- (+) Windows OS is intuitive to anyone with basic computer skills. The e-Loud program should open immediately when IPAQ powered up.
- (-) The file structure needs modification. The selection of a file is delayed as a result of how the IPAQ orders the stored files. The file contents should be clear from the name and the file arrangement should follow some convention. The files should be ordered by name, date, type etc.
- The lag time for loading files is compounded when using more than one file in the play list. A single larger file may cut down time between file selections and signal transmission.

Connectors / Jacks

- (+) Standard connectors currently used by recall systems.
- (-) Threaded plug to DC is difficult to disconnect. The plug must always be covered when operating from internal batteries (*safety*).
- (+) The input headphone jack allows the user to monitor signal from IPAQ to Xducer. This currently requires amplified headphones and is a good feature.
- (-) The installation of a 2nd headphone Jack that would provide the user with the output signal from X-ducer (better than listening directly to Wet-End). This would be a diagnostic tool used in-situ.

Power/Internal

- (+) The external 12 Volt capability is good.
- (-) The need for *constant* alternating current (AC) charging when not in use to prevent the IPAQ from losing memory is unfortunate.
- (+) The internal batteries offer more than 3 hours of power when fully charged.
- (?) Can the unit run off AC power via the trickle-charger?
- (+) The HIGH-VOLTAGE label on the transformer is a good *safety* feature.
- (-) To enhance this *safety* feature. The transformer connections should be covered with a non-conductive material (i.e. plastic cover).

Samuel V. Carroll
Naval Undersea Warfare Center
System Assessment Branch
Code 8134

APPENDIX C.

REPORT ON LOUDHAILER PROTOTYPE FIELD TEST (JUNE 2005)

by
Applied Physical Sciences Corp.

Testing of the Loudhailer Field Test Prototype

The primary objective of the prototype field test conducted in June 2005 was to assess the intelligibility of the loudhailer field test unit as a one-way diver communication device. The Naval Submarine Medical Research Lab (NSMRL) was tasked to design and execute the intelligibility testing of the loudhailer, and details of this aspect of the field test are presented in their report in Appendix E of the main report. As a secondary objective of this test sound pressure level measurements were made to verify system acoustic performance as a function of range. These measurements were made by Applied Physical Sciences Corp. (APS). This appendix presents the details of the sound pressure level measurements performed during the prototype field test conducted at the Naval Undersea Warfare Center's (NUWC) Stillwater Basin in June 2005

Sound Pressure Level Test Setup

Like the initial prototype testing, the field testing was conducted at the NUWCDIVNPT Stillwater Basin. The Loudhailer field prototype was deployed from the west end of Pier 1 using an 8-ft long aluminum extension pole to provide a standoff from the pier pilings. The water depth at the deployment area was 35 ft. The transducer array (center element) was suspended at 15 ft (source depth) for the entire test as previous testing showed no significant change in performance with source depth[1]. The loudhailer control unit was configured on the pier and connected to the transducer array. The array had a 10-lb ballast weight attached to the bottom to keep it vertical.

The received SPL was measured in the same manner as for the initial prototype test using the NUWCDIVNPT WB30 workboat and a laser rangefinder for positioning. Initial SPL measurements made using the NSMRL workboat (13 Jun 05) suffered from severe electrical interference from the on-board power inverter and will not be reported. The WB30 has a high-quality power inverter which eliminated these EMI problems.

APS used a Wilcoxon Research, Inc., H507A hydrophone to measure the acoustic pressure at six different ranges and three different depths relative to the Loudhailer source transducer array. The hydrophone sensitivity was -180.3 dB re 1 V/μPa. A Mackie 24 bit digital recorder was used to acquire the hydrophone signals and data were stored as 48 kHz Microsoft Wave files. Full-scale signal in the wave file corresponds to a voltage of 13.4 V.

The audio transmissions used for the test consisted of the same series of tones, chirps, and warning sirens used for the initial prototype test. Additional warning phrase transmissions were also recorded at one receive depth per range (15 ft) for qualitative comparison between the initial and field prototype units.

The hydrophone signals were processed using custom MATLAB programs to calculate the receive SPL as a function of frequency. The maximum one-third-octave (OTO) band levels are reported here.

Sound Pressure Level Test Results

Testing was conducted on 21 June 2005 at the NUWC Stillwater Basin. Receive locations along a line heading directly out (west) from Pier 1 were tested at nominal ranges of 50, 100, 200, 400, and 500 yds. Receive hydrophone depths of 5, 15, and 30 ft were used. The audio transmissions consisted of:

a) 2.7 kHz tone, 4 sec
b) 2.7 kHz tone, 4 sec
c) 500 Hz tone, 4 sec
d) Linear Chirp 200 – 3500 Hz, 2 sec
e) Linear Chirp 200 – 3500 Hz, 2 sec
f) Hi/Lo siren 1, 3 sec
g) Hi/Lo siren 1, 3 sec
h) Hi/Lo siren 2, 3 sec
i) Hi/Lo siren 2, 3 sec

For some runs, four messages were then transmitted including two English phrases, one Spanish phrase, and one Arabic phrase as derived from previous recordings.

A DRS-100B diver recall system was also used during the test. The system speaker was deployed to nominally a 9-ft depth (limited by the available cable length, not a system depth limitation). The DRS-100B was driven by the same audio signal as used by the *e*LOUD™ prototype. These tests were performed for both quantitative comparisons of the system loudness and for qualitative listening.

A frequency-time analysis (spectrogram) of the received SPL for signals a) through i) above from the *e*LOUD™ system at a range of 504 yds is shown in Figure C-1. Comparing this to the similar spectrogram shown in the prototype test report[1], some additional harmonic distortion is noted, the maximum sound pressure level is lower (~135 dB compared to 142 dB), and there is more low-frequency noise from flow over the hydrophone. The harmonic distortion was later attributed to the transformer used for the field prototype. It had a turns ratio that was too high which resulted in a lower than designed impedance at the output of the amplifier (the speaker load). The lower SPL is attributed in part to the lower power amplifier (200W vs. 300W or ~2 dB) but also to significantly different sound propagation conditions. The sound velocity profiles as measured in March and June of 2005 are shown in Figure C-2. The conditions in June presented a downwardly-refracting sound velocity profile while the conditions in March produced a slightly upward refracting profile. Thus the conditions in March were somewhat

more favorable for transmission of acoustic signals over long distances. Note the maximum required receive SPL for divers to hear a warning tone was estimated as approximately 132 dB from the initial requirements analysis[2].

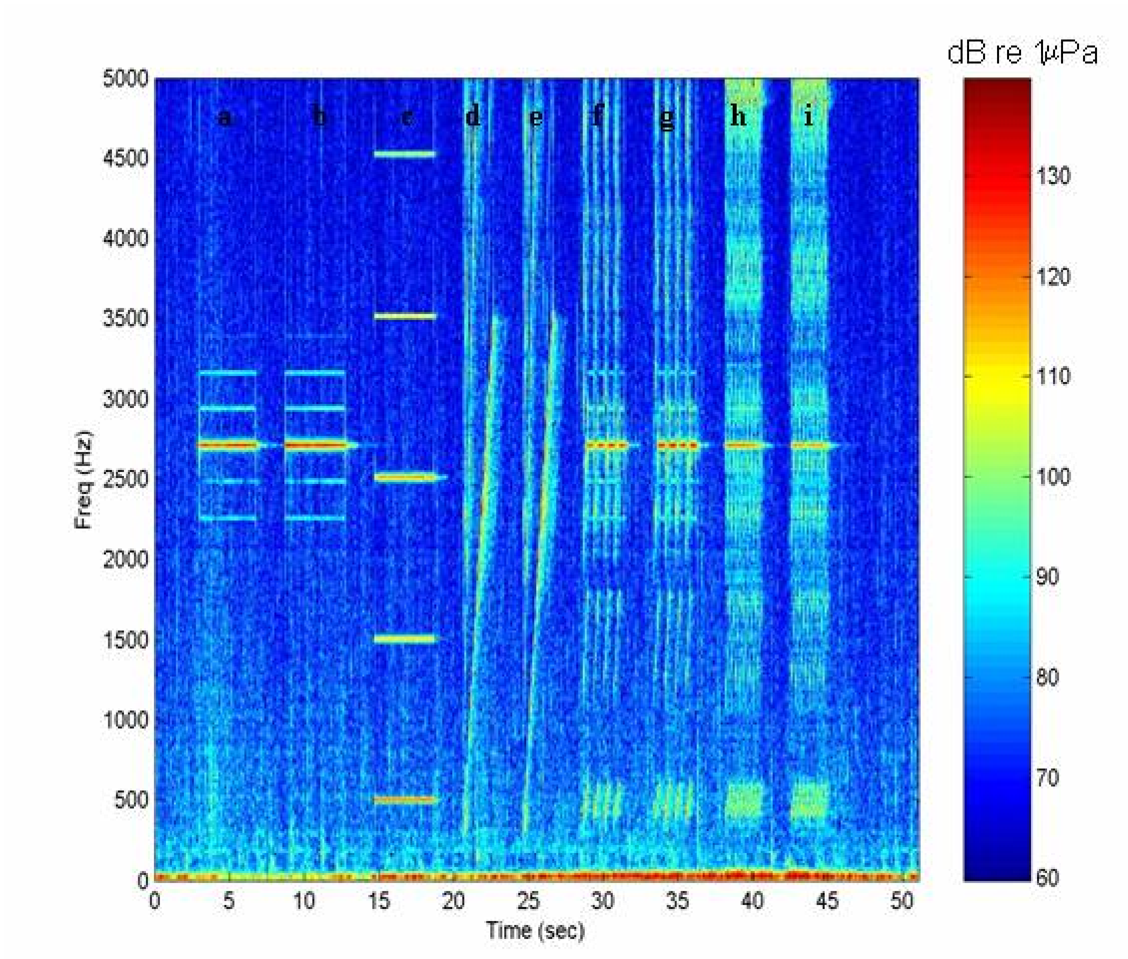


Figure C-1. Spectrogram of sound pressure received from *e*LOUD™ at 504yard range, 30-ft receive depth, 15-ft transmit depth.

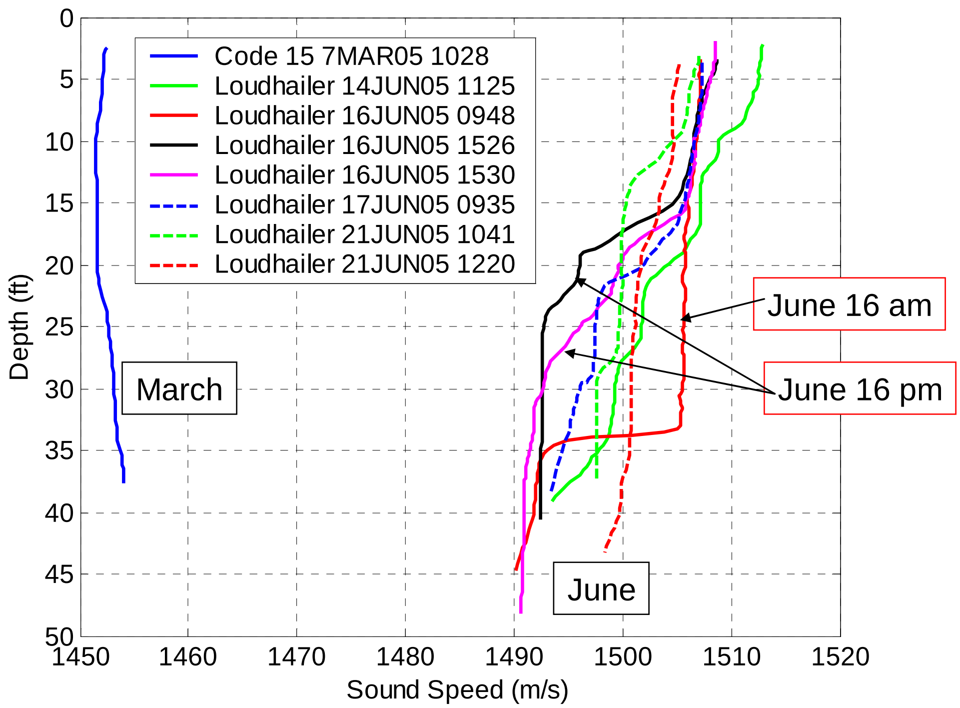


Figure C-2. Sound velocity profiles measured in NUWC Stillwater Basin in March and June of 2005.

The one-third octave (OTO) spectrum levels at the different receive hydrophone ranges and depths were then analyzed. Figure C-3 shows a comparison of the maximum received pressure spectrum for the *e*LOUD™ field test unit and the Ocean Technology Systems Diver Recall System (DRS-100B) compared to the background ambient noise level. The frequency bandwidth of the particular transducers used by the two systems is evident in the spectral response as detailed in the Transducer Final Design Report[3]. The DRS-100B uses a Lubell Labs LL916-family transducer which has a first resonance at 1 kHz. The Ocean Engineering DRS-8 transducers used by the *e*LOUD™ system have resonances at 500 and 2700 Hz. The 12 dB higher SPL generated by the *e*LOUD™ system could translate into longer effective ranges.

Similar comparisons of the *e*LOUD™ and DRS-100B systems at ranges of 200 and 400 yds are shown in Figure C-4 and Figure C-5, respectively. Based on the *e*LOUD™ receive levels for the 2.5 kHz band, the transmission loss was roughly spherical (20 log R) from 100 to 200 yds and more severe (~27 log R) from 100 to 400 yds. These propagation conditions were much different than the ~18 log R transmission loss observed in the same location during the March 2005 tests. These differences highlight the significant effect that the environment can have on the effectiveness of an acoustic transmission system.

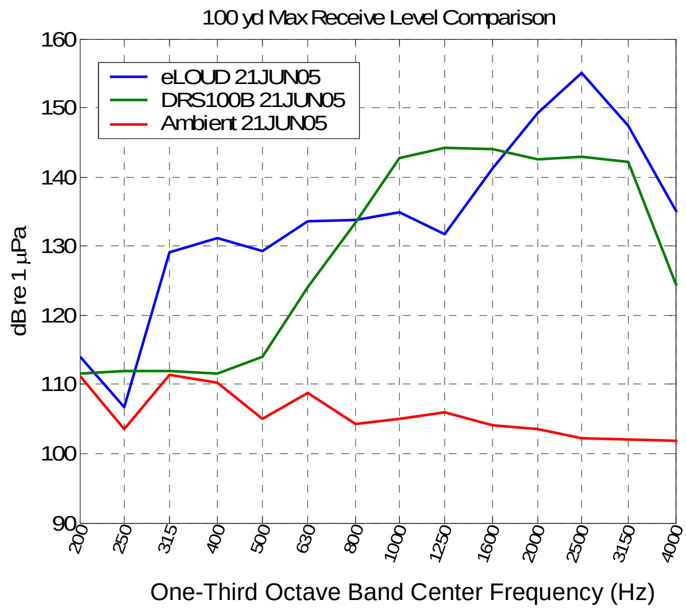


Figure C-3. Comparison of *e*LOUD™ and DRS-100B receive pressure spectra at 100 yd range (*e*LOUD™ source depth = 15 ft, DRS-100B source depth = 9 ft, and both receive depths =15 ft).

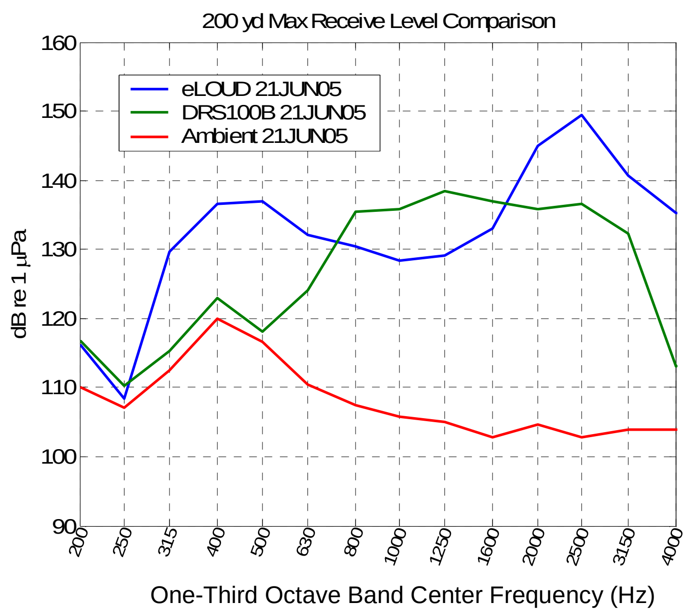


Figure C-4. Comparison of *e*LOUD™ and DRS-100B receive pressure spectra at 200 yard range (*e*LOUD™ source depth = 15 ft, DRS-100B source depth = 9 ft, and both receive depths =15 ft).

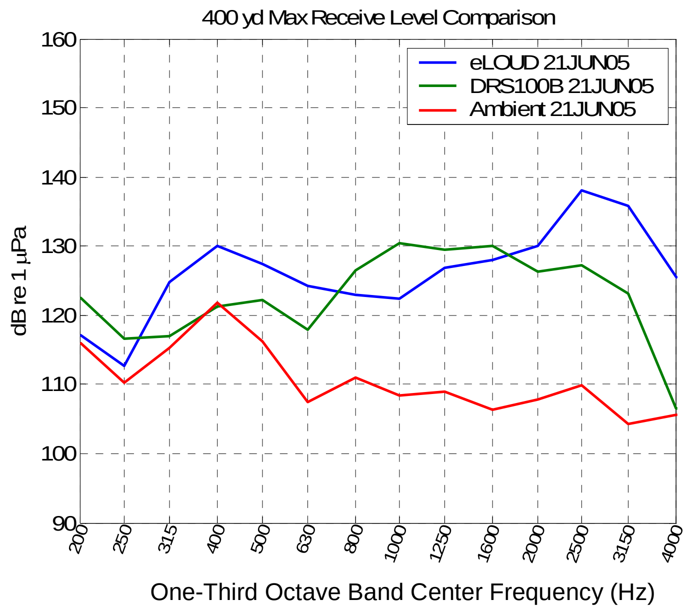


Figure C-5. Comparison of *e*LOUD™ and DRS-100B receive pressure spectra at 400 yard range (*e*LOUD™ source depth = 15 ft, DRS-100B source depth = 9 ft, and both receive depths =15 ft).

The pressure level received from the *e*LOUD™ system at 50, 100, 200, 400, and 500 yd nominal ranges is shown in Figure C-6, Figure C-7, Figure C-8, Figure C-9 and Figure C-10 respectively, including measurements for receive depths of 5, 15, and 30 ft. The results are qualitatively very similar to those from the initial prototype test in that there are approximately +/- 5 dB variations in the levels but the overall levels are lower, especially at the further ranges. For example, in June the maximum spectrum level of 136 dB was measured at 500 yds but in March the maximum was 142 dB. This difference is primarily due to increased transmission losses in June. At closer ranges the differences are smaller and can be explained by the smaller power amplifier in the June test.

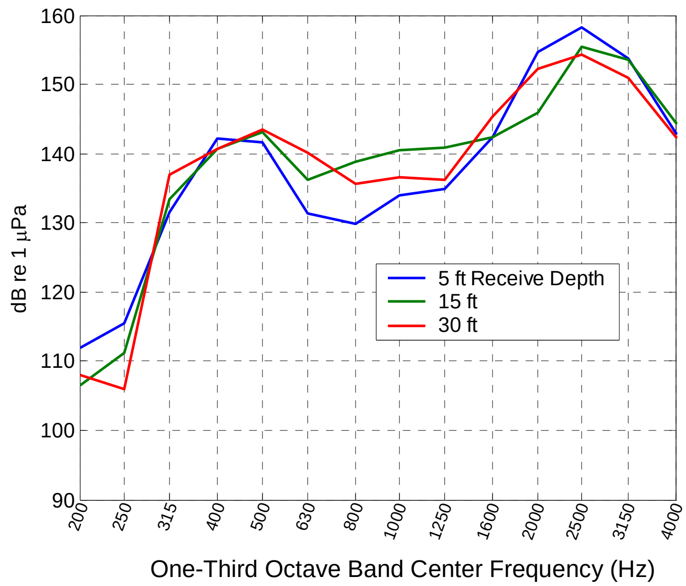


Figure C-6. Receive pressure spectrum from *e*LOUD™ system at 50 yard range.

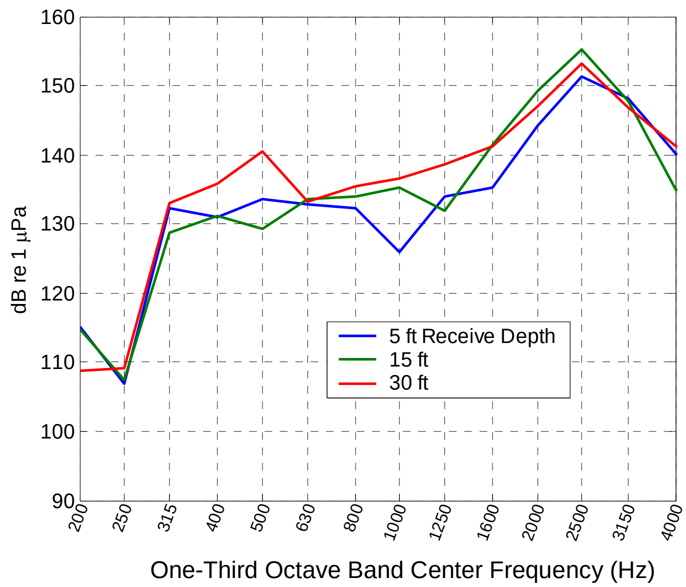


Figure C-7. Receive pressure spectrum from *e*LOUD™ system at 100 yard range.

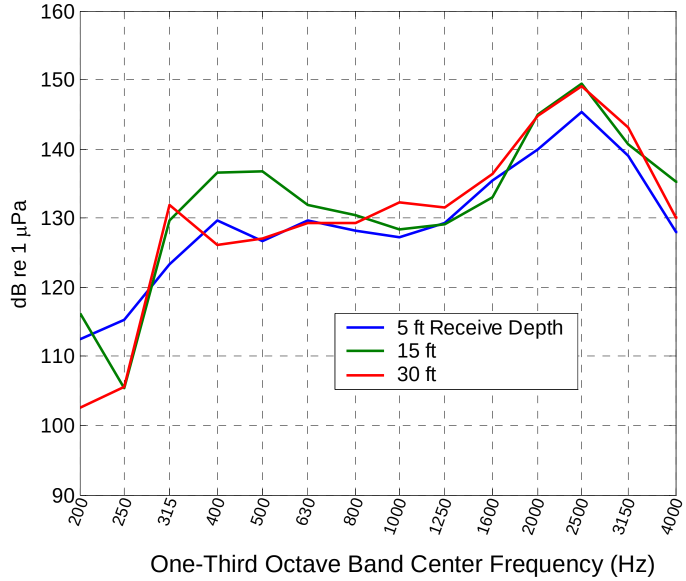


Figure C-8. Receive pressure spectrum from *e*LOUD™ system at 200 yard range.

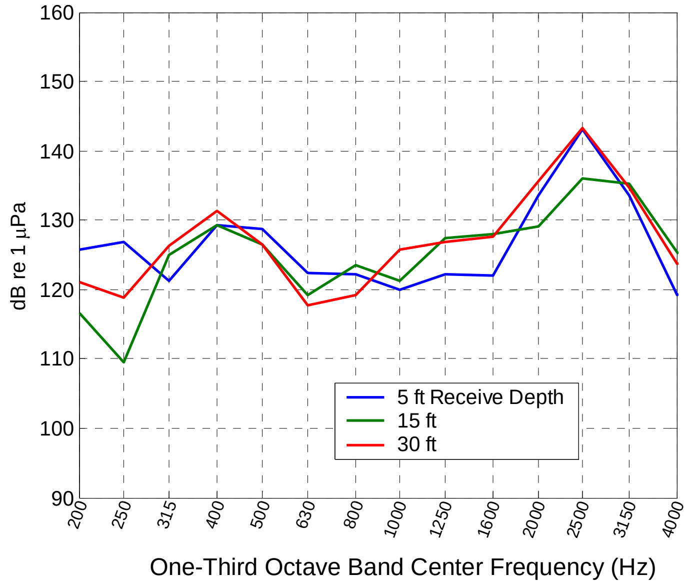


Figure C-9. Receive pressure spectrum from *e*LOUD™ system at 400 yard range.

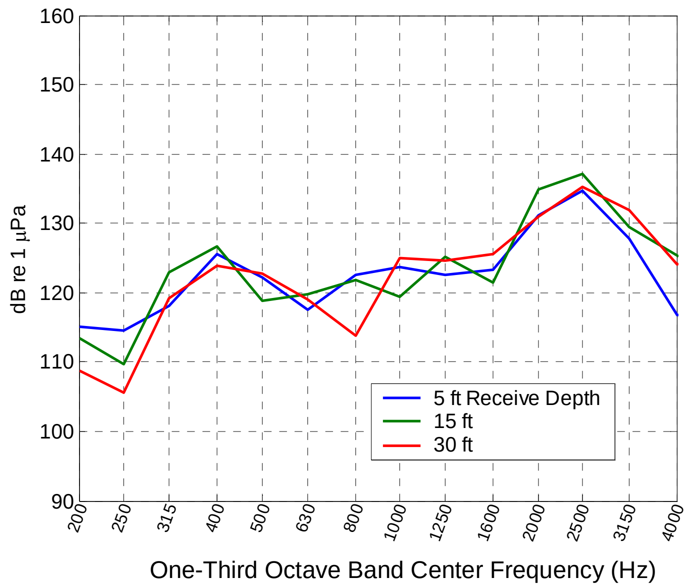


Figure C-10. Receive Pressure Spectrum from *e*LOUD™ System at 500-yard range.

References

Abraham, B, “Underwater Loudhailer Prototype Test Report,” TSWG Contract W91CRB-04-C-0057 report dated Sep 30, 2005, CDRL Data Item A005, Applied Physical Sciences Corp, New London, CT 06320.

Abraham, B., “Underwater Loudhailer Acoustic Requirements Analysis,” TSWG Contract W91CRB-04-C-0057 report dated Nov 4, 2004, CDRL Data Item A005, Applied Physical Sciences Corp, New London, CT 06320.

Abraham, B., “Underwater Loudhailer Transducer Final Design Report,” TSWG Contract W91CRB-04-C-0057 report dated March 25, 2005, CDRL Data Item A005, Applied Physical Sciences Corp, New London, CT 06320.

This page intentionally left blank.

APPENDIX D.

SPEECH INTELLIGIBILITY EVALUATION OF AN UNDERWATER LOUDHAILER PROTOTYPE

Naval Submarine Medical Research Laboratory

Technical Report TR#1244 14 December 2005

MICHAEL K. QIN, Ph.D.,

EDWARD A. CUDAHY, Ph.D.,

and ALISON AMERICA, M.A.

Approved and released by:
J. C. Daniel
CAPT, MC, USN
Commanding Officer
NAVSUBMEDRSCHLAB

Requests for this document shall be referred to Commanding Officer
Naval Submarine Medical Research Laboratory, SUBASE NLON, Box 900, Groton, CT 06349-5900.

SPEECH INTELLIGIBILITY TESTING OF

AN UNDERWATER LOUDHAILER PROTOYPE

MICHAEL K. QIN, Ph.D.,
EDWARD A. CUDAHY, Ph.D.,
and ALISON AMERICA, M.A.

Naval Submarine Medical Research Laboratory
Technical Report #1244

Research Work Unit No. 50511

Approved and released by:

J.C. Daniel, CAPT, MC, USN
Commanding Officer
NAVSUBMEDRSCHLAB

TABLE OF CONTENTS

LIST OF FIGURES

SUMMARY

The Issue(s)

To give port security forces more time to respond to potential threats, an underwater loudhailer system with significant range is needed. Current underwater loudhailers operate over an extremely limited range.

The Finding(s)

The objective of this study was to quantify and evaluate the intelligibility of speech transmitted over a promising new prototype (*e*LOUD™). Findings of the current study indicate that the prototype is capable of transmitting a closed set of verbal warning-phrases to a range of 400 yards with > 90% intelligibility, with no diver discomfort reported at 50 yards. Trends in the speech intelligibility data, measured received-levels, and articulation index predictions suggest that adequate intelligibility of well-known phrases is possible to 500 yards.

The Application(s)

*e*LOUD™ appears to be a reliable and robust system for projecting intelligible American-English warning messages to significant ranges. We recommend distributing recordings of standard U.S. Coast Guard (CG) warning tones and messages among diving instructors, so they can familiarize their students to the CG warnings.

Administrative Information

This work was conducted under Work Unit #50511, entitled "Speech Intelligibility Testing of an Underwater Loudhailer Prototype." The opinions or assertions contained herein are the private ones of the authors, and are not to be construed as official or reflecting the views of the Department of the Navy, Department of Defense, or the United States Government. This research has been conducted in compliance with all applicable Federal Regulations governing the Protection of Human Subjects in Research. This Technical Report was approved on 14 December 2005, and designated as NSMRL Technical Report TR#1244.

ABSTRACT

The objective of this study was to quantify and evaluate the intelligibility of speech transmitted to divers over a prototype underwater loudhailer (*e*LOUD™). Findings of the study indicate that the prototype is capable of transmitting a closed set of verbal warning-phrases to a range of 400 yards with > 90% intelligibility, with no diver discomfort reported at 50 yards. Trends in the speech intelligibility data, measured received levels, and articulation index predictions suggest that adequate intelligibility of well-known phrases is possible to 500 yards. The *e*LOUD™ prototype appears to be a reliable system for projecting intelligible American-English warning messages to significant ranges. We recommend distributing recordings of standard CG warning tones and messages among diving instructors, so they can familiarize their students to the CG's underwater audio warnings.

ACKNOWLEDGEMENTS

We deeply appreciate the efforts of the divers of the CG Maritime Safety and Security Teams (MSST), the Naval Undersea Warfare Center: Division Newport (NUWCDIVNPT), and the Naval Submarine Medical Research Laboratory (NSMRL), without whom this study would have been impossible. The authors would also like to acknowledge the critical assistance provided by Ric Walker of the Research and Development Center (RDC); Roy Manstan, Sam Carroll, and Jack Hughes of the Naval Undersea Warfare Center's (NUWC) Engineering & Diving Support Unit; Lieutenant Greg Duncan of the CG's MSST-Chesapeake; and last but not least, Dr. Bruce Abraham from Applied Physical Sciences Corp.

"When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a very meager and unsatisfactory kind."

William Thomson, Lord Kelvin (1824-1907)

INTRODUCTION

This research stems from the requirement to provide enhanced security for critical maritime assets. The focus of the system under test is part of an integrated system used to deter divers from entering restricted areas. The CG has deployed a number of Integrated Anti-swimmer Systems (IAS), capable of detection, notification, and interdiction of potentially hostile divers. However, the current system for warning-message transmission (i.e., notification) has an extremely limited range, often as short as 25 yards. To give port security forces more time to respond to potential threats, an underwater loudhailer with greater range is needed. Although speech projection with sufficient range is the engineering issue, message intelligibility is the key to the successful operational deployment of the subsystem. Recently, the Applied Physical Sciences Corporation developed a promising underwater loudhailer system (*e*LOUD™). The objective of this study was to quantify and evaluate the intelligibility of speech transmitted to divers over a prototype of *e*LOUD™.

BACKGROUND

There is very little research on underwater speech intelligibility because divers typically do not speak through water. The presence of a regulator in the mouth of a SCUBA diver makes articulation extremely difficult, so divers typically rely on hand signals and slate boards for communication. A number of underwater loudspeakers have been developed. These underwater loudspeakers have been used in synchronized swimming and as diver recall systems over the years. However, the ranges of these systems are relatively short, with intelligible transmission breaking down over distances as short as 25 yards.

There was an attempt to improve speech intelligibility for the diver recall system (DRS) by applying a weighting function, based on underwater hearing threshold data from Parvin and Nedwell (1995). This did improve the intelligibility range from 25 yards to 50 – 75 yards (Rehn, personal communication), but performances fell far short of the desired range for port security applications (500 yards).

More recently, the Applied Physical Sciences Corporation developed an underwater loudhailer system by the name of *e*LOUD™. The system was pilot tested in early March 2005 and received favorable subjective impressions. This study was initiated to provide quantitative data regarding the ability of *e*LOUD™ to deliver intelligible speech over long ranges.

EXPERIMENTAL METHODS

The goal of the present study was to systematically quantify and evaluate the intelligibility of speech transmitted over a prototype *e*LOUD™. Identification accuracy of monosyllabic words and brief phrases was used as the metric to quantify the effectiveness of *e*LOUD™. Standard in-air speech testing techniques were modified for the diving environment.

Subjects

Twelve U.S. Navy trained divers (11 male, 1 female) with normal hearing (audiometric thresholds were <25 dB HL between 125 and 8000 Hz) from three different commands (MSST, NUWCDIVNPT, and NSMRL) participated in this study. It is known that the intelligibility of speech depends strongly on the listener's experience with the target language; therefore, non-native speakers of American English were excluded from the present study.

System Under Test (*e*LOUD™)

The *e*LOUD™ (Enhanced Underwater Loudhailer) is an underwater sound transmission system intended for use as a diver-warning system (due to the proprietary nature of eLOUD, only a broad description of the system is provided here). The system under evaluation was a prototype recently developed by the Applied Physical Sciences Corporation (New London, CT). The *e*LOUD™ is designed to be a battery-operated, high fidelity, one-way, audio-band underwater acoustic transmission system, capable of transmitting warning tones and voice messages to hooded divers using open- or closed-circuit breathing apparatus over ranges exceeding 500 yards. The system is designed to transmit pre-recorded messages or live messages via a

microphone. The messages are intended to provide warnings/instructions to divers, and thus need to be clearly understood.

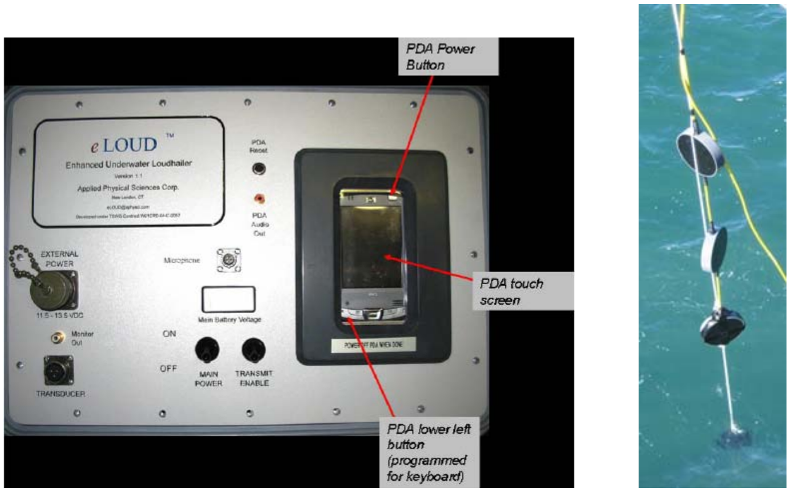


Figure D-1. The photographs show the control unit and the vertical three-transducer array just prior to deployment (photographs courtesy of Bruce Abraham, Applied Physical Sciences Corporation).

The main system components are the Control Unit and the Transducers. Figure D-1 shows a photograph of the control unit and a photograph of the transducer array. To focus the sound transmissions about the horizontal plane and to minimize surface and bottom reflections, *e*LOUD™ employs a vertical transducer array of three transducers.

Speech Material

The usefulness of a system evaluation is considerably influenced by the degree to which the experimental conditions are representative of the conditions of the intended use. Given the dual capabilities of *e*LOUD™ to play pre-recorded messages as well as transmit live speech (via the push-to-talk microphone), we felt that the system should be evaluated for its ability to deliver the anticipated CG warning-phrases and general speech (Miller et al., 1951). Two speech corpora were used in the present study: one focused on single word identification (the Northwestern University Auditory Test No. 6); the other focused on sentence-level speech intelligibility (CG port security warning phrases).

<u>Single-word identification test</u>: The Northwestern University Auditory Test No. 6 (NU-6) is a word recognition test routinely used in audiologic assessment. The NU-6, based on the concept of phonemic balance, is composed of four lists of 50 monosyllabic words. Each word in the list is preceded by the carrier phrase, “Say the word ….” For our purposes, the four 50-word lists were split into eight 25-word lists. The divers were instructed to respond by writing down the target word on a plastic slate with a grease pencil, rather than verbally repeating the target word. The NU-6 audio recording used in this study was purchased from AUDiTEC™ of St. Louis, a professional recording company serving the needs of audiologists. The NU-6 was chosen to simulate the potential of transmitting low-context live speech, as well as to provide a point of

comparison between the current underwater study and the wealth of studies on in-air word recognition.

Sentence-level intelligibility test: In addition to the single-word test, a sentence-level intelligibility test was also conducted. The sentence-level test consisted of the various verbal warning-phrases being considered by the CG (Appendix A). The warning-phrases were 5 words or less in length (i.e., ~2.5 seconds in duration). The test phrases were selected randomly from the warning-phrase corpus.

Experimental Conditions

Single-word test: The divers were tested at 6 locations (2 ranges x 3 depths). Based on the performance results of Divers 001, 002, and 003 from Day-1 of the study, the range of the Single-word tests were set at 50 yards and 100 yards. At each range, the divers were tested at three separate depths (5, 15, and 30 feet). Single-word intelligibility at each test location was determined by the percent-correct identification of a 25-word list. Separate word lists were used for each of the 6 test locations.

Warning-phrase test: The divers were tested at 9 locations (3 ranges x 3 depths). Based on the preliminary results of Divers 001, 002, and 003 from Day-1 of the study, the range of the Warning-phrase tests were set at 50 yards, 100 yards, and 400 yards. For each range, the divers were tested at three separate depths (5, 15, and 30 feet). Based on preliminary results that indicated warning-phrases were perfectly intelligible at close ranges, at the 50-yard and 100-yard range sentence-level speech intelligibility was measured with a set of 5 warning-phrases at each depth. At the 400-yard range, speech intelligibility was determined by a set of 10 warning-phrases, at each depth. In an effort to reduce the amount of time divers spend in the water, testing efforts were focused on sentence-level intelligibility at the longer range and single-word identification at the shorter ranges.

Stimulus Presentation

In the present study, each stimulus was preceded by two half-second alert tones (500 Hz and 2700 Hz). Although alert tones are not part of the standard in-air speech intelligibility test procedure, they are an integral part of the intended *e*LOUD™ deployment protocol. We chose to closely mirror the intended utilization of the system in our experiments, to more accurately extrapolate the results to real world use.

Experimental Setup

All tests were performed in the Narragansett Bay (see Figure D-2), at NUWCDIVNPT located in Newport, R.I. The diving was performed in accordance with the provisions of the U.S. Navy Diving Manual (Rev 4, Change A, 2001). All diving operations were conducted under the control of the NSMRL Diving Officer.

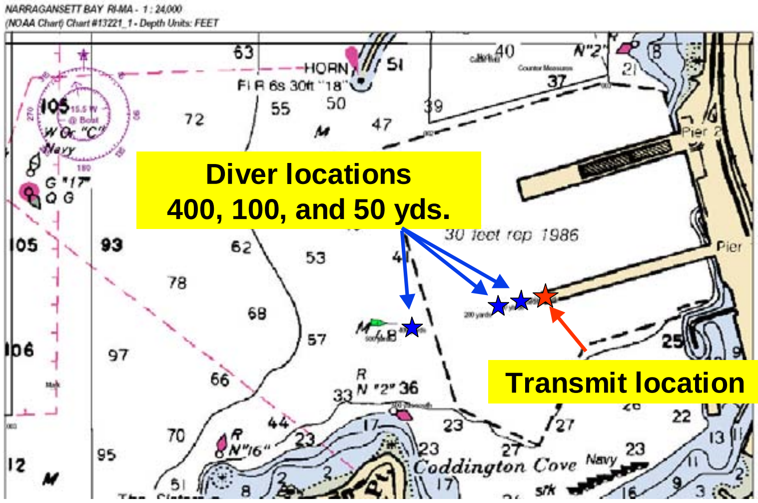


Figure D-2. Illustration of the Narragansett Bay, where all tests were performed.

Pier-1 at NUWCDIVNPT was selected as the deployment platform for the *e*LOUD™ prototype. The water depth is ~40 feet at the end of the pier. A cantilever beam with a pulley was attached to the end of the pier for easy deployment of the transducer array. Throughout the study, the center of the transducer array was kept at a depth of 15 feet.

Figure D-3. Photograph of the NSMRL dive boat and her crew getting into position.

The divers were taken to the desired range from Pier-1 by a dive boat. A laser range finder was used to determine the range of the dive boat from Pier-1. When in position, the dive boat anchored and shut off its engines. Divers then dived to the desired depth, with a dive slate and grease pencil. All divers wore a standard 7 mm neoprene wetsuit with hood and open-circuit breathing apparatus (see Figure D-4).

Figure D-4. Photograph of a diver recording his response on the dive slate, while hanging from a vertical descent line.

During testing, the divers were suspended vertically from a weighted descent line off the side of the dive boat, with knots indicating the test depths (i.e., 5 ft, 15 ft, and 30 ft). The divers were instructed to respond to the sound stimuli while maintaining their dive depth by wrapping their legs around the descent line. The divers were also instructed to hold their breath after hearing the warning tones and attend to the speech stimuli to follow. They were allowed to breathe normally when writing down their responses and while waiting for the alert tones.

Each diver participated in the study on two separate days (i.e., a training session and a testing session). All experimental conditions were run on both days. The word and phrase lists were randomized, to avoid having any diver receive the same lists at the same location on the separate days.

RESULTS

The *e*LOUD™ performed reliably, despite long (10-12 hour) test days and high ambient temperature (> 90° F). Tests were completed without any mechanical failures on the part of *e*LOUD™.

System performance

Acoustic transmissions by *e*LOUD™ were measured at 15 positions (5 ranges x 3 depths). The boat, with a receiving hydrophone, was positioned in the same manner as described above (Experimental Setup section). The hydrophone was then lowered into position. All measurements were taken with the boat engines shut off. Figures 5-9 show the measured 1/3 octave band received sound pressure level as a function of frequency, with the measuring hydrophone's depth as a parameter. The figures show that hydrophone depths had little-to-no effect on received levels.

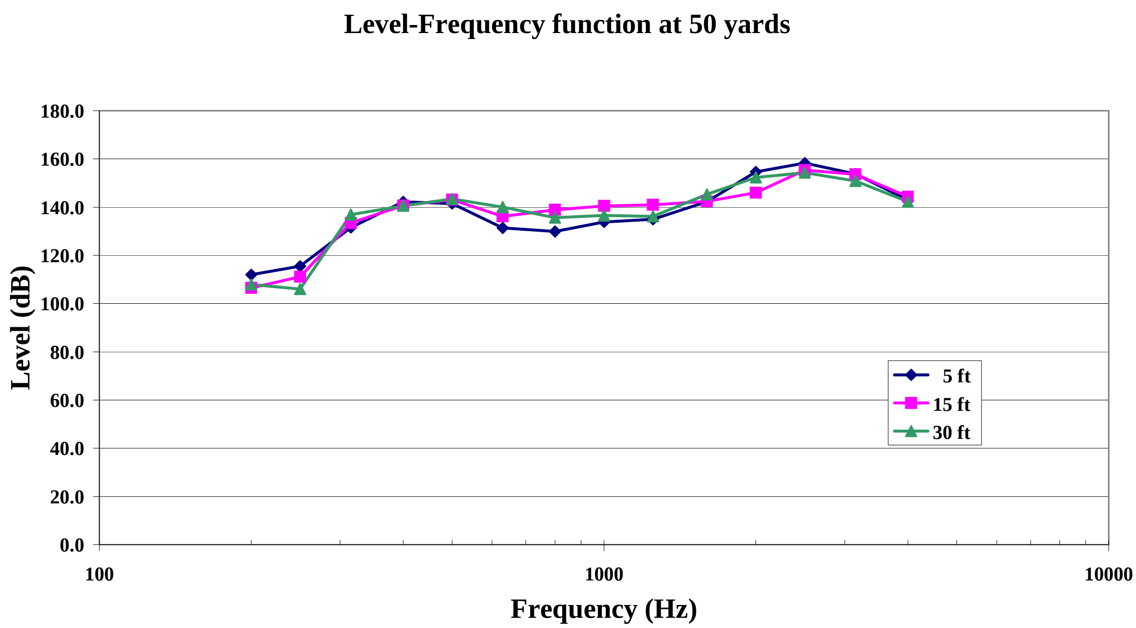


Figure D-5. Received sound pressure level (1/3 octave band) as a function of frequency measured 50 yards from the source, with hydrophone depth as a parameter.

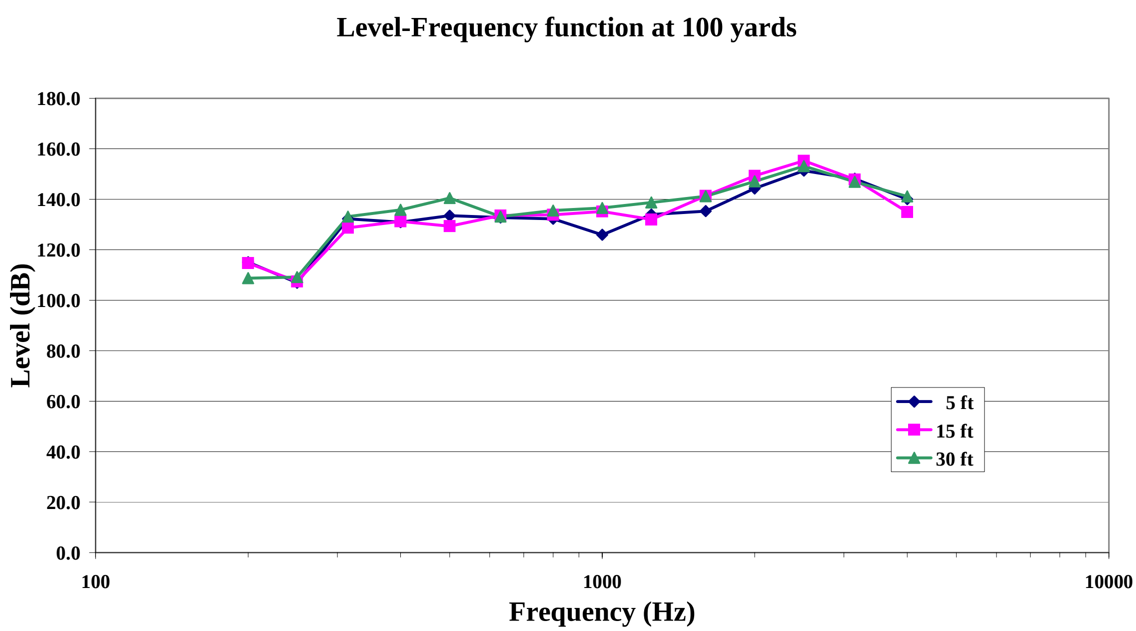


Figure D-6. Received sound pressure level (1/3 octave band) as a function of frequency measured 100 yards from the source, with hydrophone depth as a parameter.

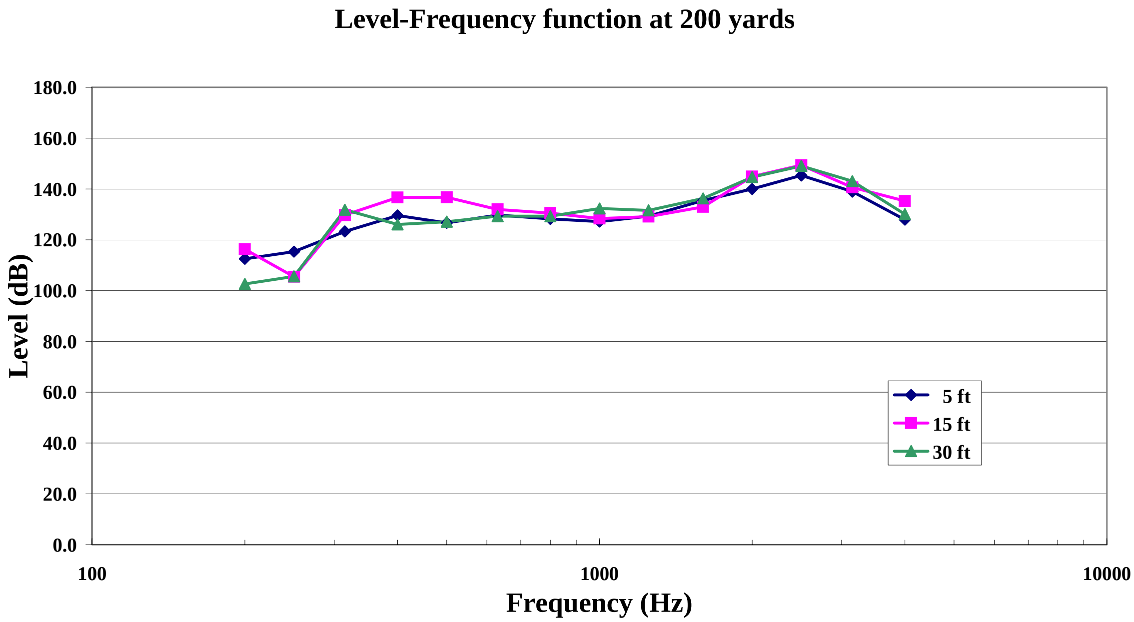


Figure D-7. Received sound pressure level (1/3 octave band) as a function of frequency measured 200 yards from the source, with hydrophone depth as a parameter.

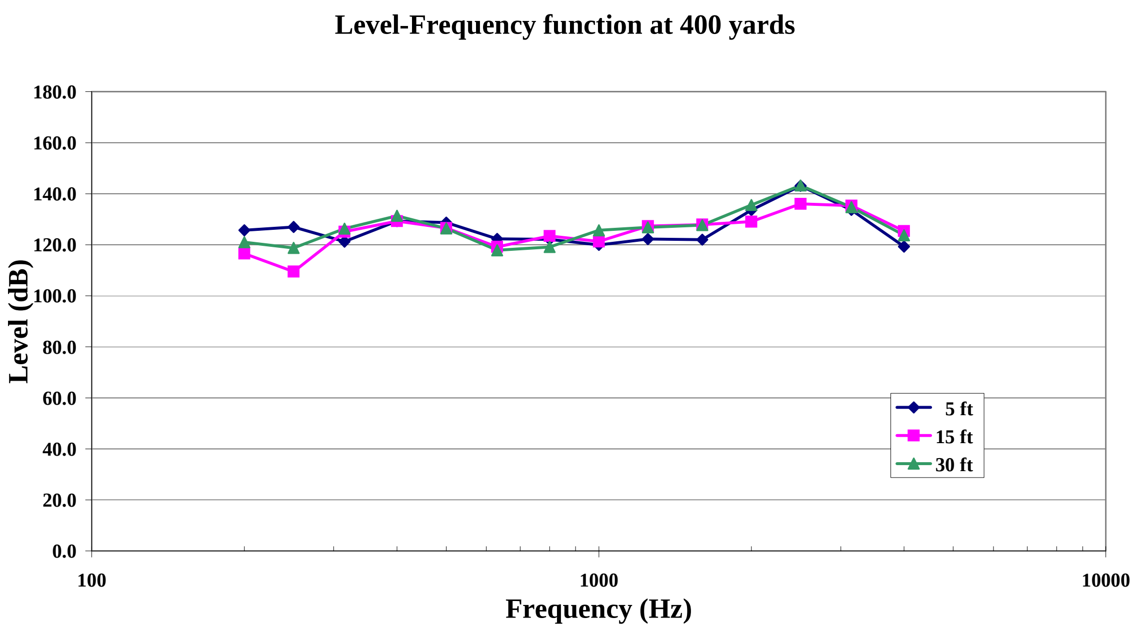


Figure D-8. Received sound pressure level (1/3 octave band) as a function of frequency measured 400 yards from the source, with hydrophone depth as a parameter.

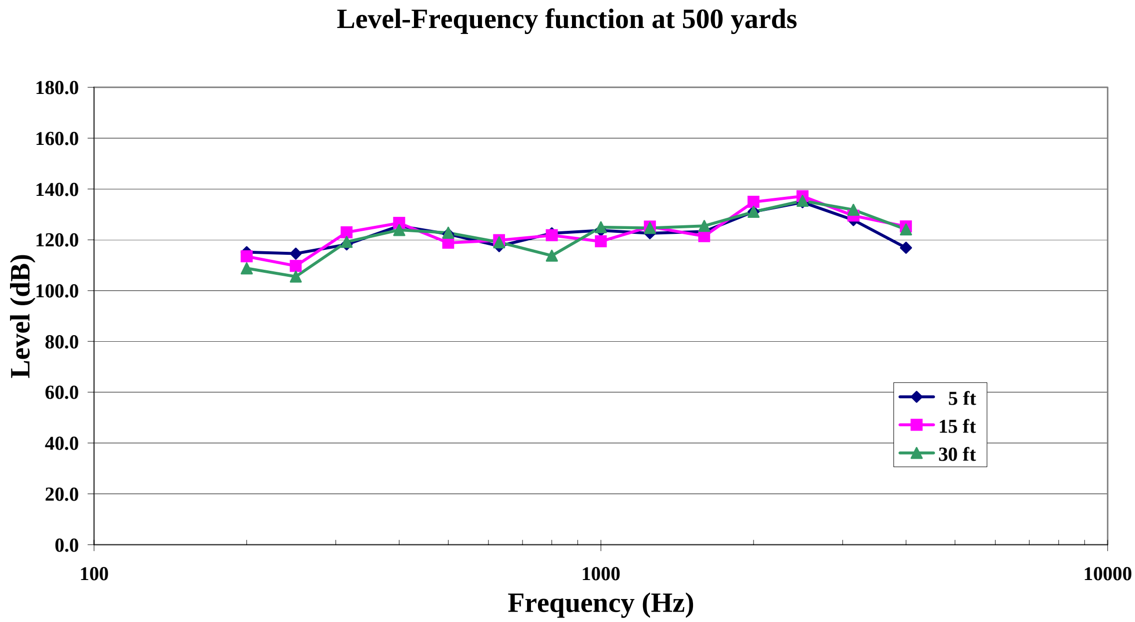


Figure D-9. Received sound pressure level (1/3 octave band) as a function of frequency measured 500 yards from the source, with hydrophone depth as a parameter.

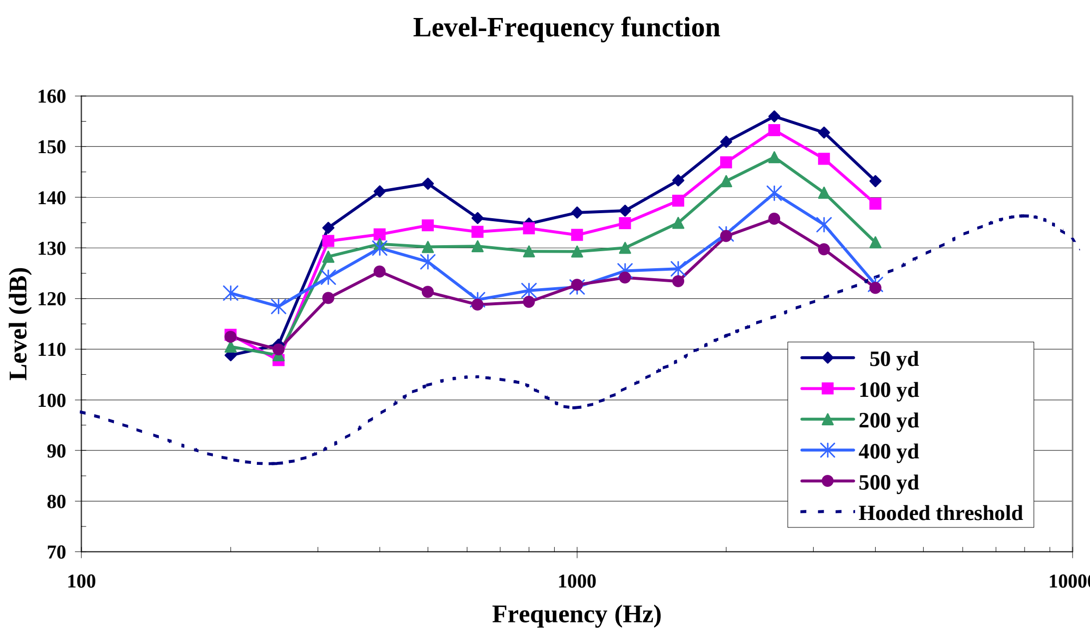


Figure D-10. Received levels as a function of frequency and receiver range averaged across depth are plotted in solid lines. Average threshold of hearing of hooded divers as a function of frequency is plotted as the dotted line.

In general, received levels across depth were reasonably consistent, so the mean received levels (averaged across depth) as a function of frequency and range are plotted in Figure D-10. The

figure illustrates a consistent attenuation of the spectra as a function of range (i.e., the overall spectral shape is minimally affected as a function of range). It is also important to note here that out to 500 yards the received levels are in general well above the threshold of hearing of a hooded diver (Figure D-10). Furthermore, the received level spectrum at 500 yards is similar to the received level spectrum at 400 yards. This fact is important as we discuss, in later sections, the extrapolation of diver speech reception performance at 500 yards.

Effects of range and depth on speech intelligibility

Figure D-11 shows the mean percent correct of single-word identification and standard error of mean, with the distance of the diver from the source and the depth of the diver as parameters. To investigate trends in the data, a repeated-measures ANOVA with two within-subject factors (range and depth) was conducted. A statistically significant difference was found between 50-yd and 100-yd range ($F_{1,11} = 9.671$, $p<0.05$), as well as a statistically significant effect of depth ($F_{2,22} = 7.444$, $p<0.05$), but no interaction ($F_{2,22} = 3.080$, $p>0.05$). This finding of a statistically significant difference in range can be explained by the received-level differences, as discussed above.

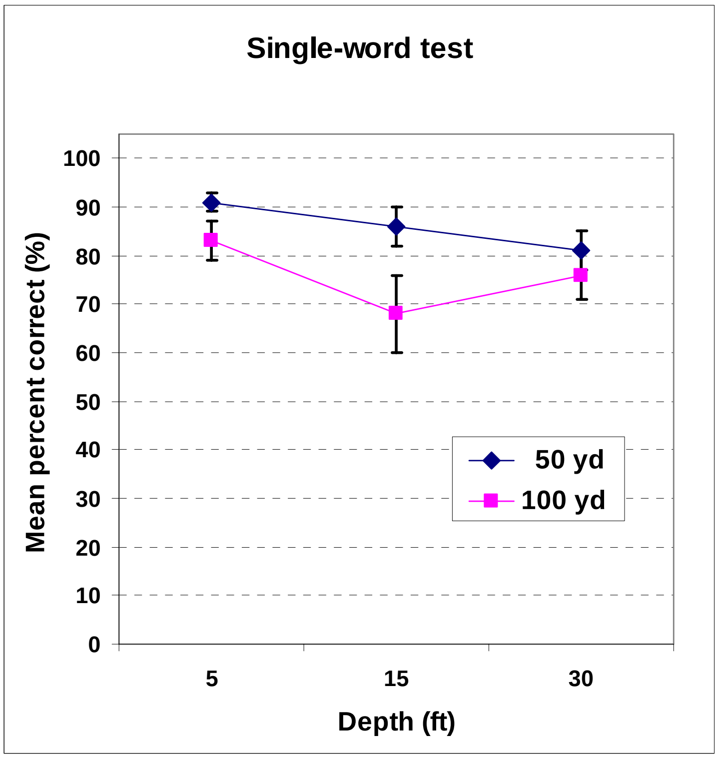


Figure D-11. Mean percent correct (±SEM) of single-word identification as a function of diver depth with the range of the diver from the source as a parameter.

The statistically significant difference in depth, however, is inconsistent with the received-level measurements. Prior to performing the study, we postulated that if speech intelligibility were affected by diver depth, it would increase as a function of depth. This hypothesis was motivated by earlier findings that neoprene hoods attenuate sounds less at greater depths. However, the

results (Fig. 11) show a decrease in intelligibility. A possible explanation for this finding could be found in the presence of the regulator/bubble noise.

It is generally reported by divers that in the event of detecting a sudden waterborne sound, they would investigate the nature of the sound by temporarily holding their breath and allowing exhaled air bubbles to clear the area (i.e., to minimize potential bubble-noise interference). To best simulate the real world situation, divers were instructed to hold their breath after hearing the first warning tone. However, if the divers did not begin holding their breath immediately after the first warning tone, then bubble noises may persist well into the stimulus presentation. This is less of an issue at the 5-ft depth, because the bubbles can quickly travel to the surface and cease to contribute to the background interference. At the 15-ft and 30-ft depths, on the other hand, the bubbles cannot quickly travel to the surface and thus continue to contribute to the background noise as they ascend. The varying amount of time needed for the bubbles to ascend to the surface and cease adding to the interference, may account for the adverse effect of depth on speech intelligibility.

Figure D-12 shows the mean percent correct of warning-phrase identification and the standard error of means, with the range of the diver from the source and the depth of the diver as a parameter. When a repeated-measures ANOVA with two within-subject factors (range and depth) was conducted, no statistically significant difference was found between the 3 depths ($F_{2,22} = 2.416$, $p>0.1$). In addition, no effect of range ($F_{2,22} = 2.140$, $p>0.1$), and no interaction ($F_{4,44} < 1$, n.s.), was seen. The high levels of warning-phrase identification performance (>90%) produced a ceiling effect and led to the lack of significant effects of range and depth.

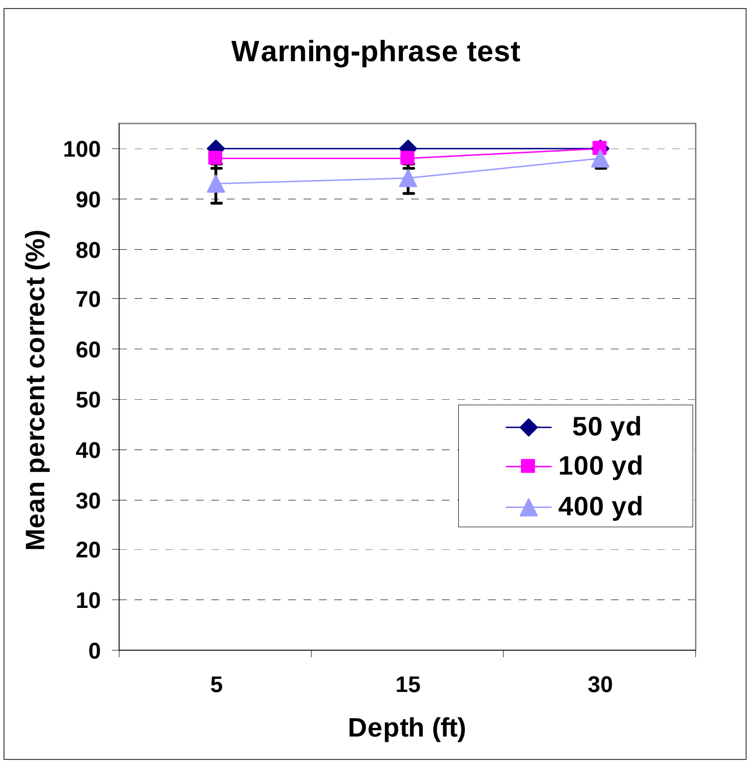


Figure D-12. Mean percent correct (±SEM) of warning-phrase identification as a function of diver depth with the range of the diver from the source as a parameter.

Effects of range and test material on speech intelligibility

Figure D-13 shows mean percent-correct identification and the standard error of means as a function of the range of the diver from the source, with the type of speech material as a parameter. The figure shows that the identification of single words is consistently poorer than that of warning phrases. Furthermore, while warning-phrase reception remains above 90 percentage points at 400 yards, single-word reception dropped by 10 percentage points from 50 yards to 100 yards.

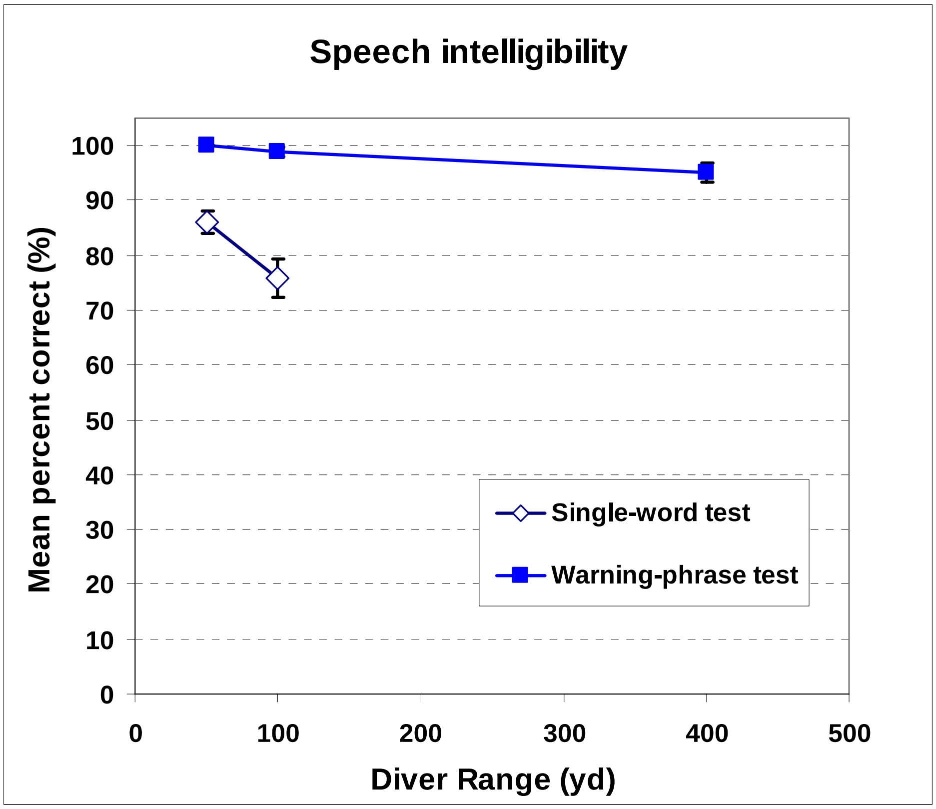


Figure D-13. Mean percent correct (±SEM) identification as a function of the range of the diver from the source, with the type of speech material as a parameter.

Dive-safety constraints[5] prevented us from measuring speech intelligibility out to 500 yards. However, based on the speech intelligibility data at 400 yards (> 90% accuracy) and the measured received-level difference between 400 yards and 500 yards (Figure D-9), articulation index (AI) predictions[6] suggest that under low ambient noise conditions adequate intelligibility of the CG warning phrases is possible out to 500 yards with the *e*LOUD™ system.

---

[5] Measuring out to 500 yards would have taken us outside the breakwater, an operation deemed extremely precarious by the Master Diver.

[6] Articulation Index (AI) is a statistical method that attempts to predict speech intelligibility from the acoustic representation of the speech signal. In the current study, the measured received levels and previously measured diver-hearing thresholds were used in the AI calculation.

DISCUSSION

Findings of the current study indicate that the *e*LOUD™ is capable of transmitting a closed set of verbal warning phrases to a range of 400 yards with > 90% intelligibility, with no diver discomfort reported at 50 yards. Due to dive-safety constraints, diver speech intelligibility was not measured at the 500-yard range. However, trends in the speech intelligibility data, measured received levels, and articulation index predictions suggest that adequate intelligibility of well-known phrases is possible to 500 yards. It should be noted that in the current study intelligibility measures were performed with a single presentation of the warning phrase. Multiple repeated transmissions of the same warning message (i.e., the expected deployment condition) would result in greater speech reception at the same ranges.

The results of the single-word identification test, on the other hand, suggest that in live-transmission mode (i.e., via the push-to-talk microphone) intelligibility can drop as low as 76% at a range of 100 yards, with the effects of depth playing a possible role. It is unfortunate that time did not permit gathering additional data at greater ranges for the single-word identification task. Had we been able to obtain the speech reception threshold (i.e., the point at which the speech intelligibility is at 50%) *e*LOUD™'s performance could have been more thoroughly characterized. Furthermore, the exact nature of the effects of depth on intelligibility warrants further study.

It is important to note that the current study was conducted in a low noise environment (e.g., little-to-no boat traffic in the vicinity). In deploying any loudhailer system, special care should be given to reduce the noise in the vicinity of the diver(s). As an example, during warning message transmission, intercept boat operators near the diver(s) should shut off their engines to reduce the local noise level. In the presence of high environmental noise, the projection range of intelligible speech can be greatly reduced. The amount of intelligibility reduction will be a function of the amount of noise. In the extreme case, total loss of intelligibility is possible. The detrimental effects associated with reduced signal-to-noise ratio can be greatly minimized by placing the signal source closer to the diver (e.g., deploying *e*LOUD™ from a boat near the diver).

It is also important to note that the current intelligibility study was conducted using only native speakers of American-English. It is known from in-air speech tests that non-native speakers have greater difficulty than native speakers in understanding speech in complex auditory environments, with differences ranging from 10 percentage points to 80 percentage points (Nabelek and Donahue, 1984; Takata and Nabelek, 1990; Mayo et al., 1997). This implies a message that is 100% intelligible to a native speaker of American-English could be only 20% intelligible to a non-native speaker, depending on the non-native speaker's proficiency. It is reasonable to project the "non-native speaker" deficit to the underwater environment.

Furthermore, the current study used exclusively American-English stimuli. While these results may extrapolate reasonably well to other Romance languages, with similar phonemic qualities, it is unclear how the system will perform with languages with significantly different phonemic qualities (e.g., Arabic and Chinese). Further study is warranted.

In summary, *e*LOUD™ appears to be a reliable and robust system for projecting intelligible American-English warning messages out to significant ranges. In addition, we recommend distributing recordings of standard CG warning tones and messages among diving instructors, so they can familiarize their students to the CG's underwater audio warnings.

REFERENCES

Mayo, L. H., Florentine, M., and Buus, S. (1997). "Age of second-language acquisition and perception of speech in noise," J Speech Lang Hear Res 40, 686-693.

Miller, G. A., Heise, G. A., and Lichten, W. (1951). "The intelligibility of speech as a function of the context of the test materials," J Exp Psychol 41, 329-335.

Nabelek, A. K., and Donahue, A. M. (1984). "Perception of consonants in reverberation by native and non-native listeners," J Acoust Soc Am 75, 632-634.

Parvin, S. J., and Nedwell, J. R. (1995). "Underwater sound perception and the development of an underwater noise weighting scale," Underwater Technology 21, 12-18.

Takata, Y., and Nabelek, A. K. (1990). "English consonant recognition in noise and in reverberation by Japanese and American listeners,: J Acoust Soc Am 88, 663-666.

Appendix D(1)

Warning phrases used in the present study.

01) United States Coast Guard
02) Attention diver surface now
03) Come to the surface
04) This is a restricted area
05) Stop now and surface
06) United States Navy restricted zone
07) Do not enter this area
08) This is your final warning
09) You must surface now
10) Warning. Warning. Restricted area
11) Stop. You will be harmed.
12) We will use deadly force
13) Surface with hands up
14) Stop swimming and surface
15) This is your first warning
16) Last warning. Surface immediately
17) Attention swimmer. Stop now.
18) Halt. No diving allowed
19) This is your second warning.
20) Warning. Bad things will happen.
21) Underwater loudhailer test four
22) Raise your right hand
23) Raise your left hand
24) Take off your mask
25) Speak to me in English

APPENDIX E.

LOUDHAILER SPECIFICATIONS AND DRAWINGS

*e*LOUD™ Specifications (Version 1.2)

Electrical

Battery:	12V, 12Ah sealed lead acid (SLA)
Battery Charger:	115V AC SLA "smart" charger, 1.5A current, connected via external cable to front panel connector
Fuses:	One 20A ATO-style fuse, one 1A, 5mm bullet-type fuse
External Power:	11.5 to 13.5 V DC, 10A max current with main battery installed, 20A max current without main battery installed, connected via external cable with cigarette lighter adapter to front panel connector
Audio amplifier:	400W, 4Ω class D amplifier, 88% efficiency
Stepup transformer:	Edcor custom transformer
PDA Power:	Supplied via internal 12V auto adapter using DC-DC converter
Operation time:	At least 2 hours using 25% duty cycle (actual over 4 hours with fully charged battery)
Recharge Time:	Depends on battery drain:

Hours of use at 25% duty cycle	Approx. Recharge Hours
1	1.75
2	3.5
3	5.25
4	7

Mechanical

Control Unit:
Weight 35 lb
Size 18.25" by 14" by 6.75"
Manual vent (normally closed)
Case color: Gray with adhesive labels

Transducer Case:
Weight 25 lb
Size 19.5" by 15" by 7"
Manual vent (normally closed)
Case color: Gray with adhesive labels

Transducer Array:
Three elements, 24" center-to-center spacing, wired in parallel
Cable length: 75 ft (Suprene 105, 18 ga)
Array to be deployed vertically, maximum recommended 15^{o} tilt angle (note ballast weight not included)
Support line: ¼" double braided nylon, maximum load 100 lb

Computer / Software

PDA Computer:	Hewlett Packard hx2400 series or similar running Windows Mobile 5.0 operating system. PDA must have at least one Secure Digital™ (SD) slot. PDA must have non-volatile (flash) memory and be capable of operating without the PDA battery installed.
SD Card:	256 MB or larger Secure Digital™ Card
eLOUD™ Control Software:	Custom software, current version is 1.2
Sound File Format:	Microsoft Wave format, 11,025 Hz sample rate, 16 bit mono, maximum non-dimensional level of 0.95 (integer of 31130).

Environmental

Control Unit:	Operating temperature -10°F to 100°F, Charging temperature 4°F to 100°F Humidity 100% with case vent closed Submersion depth 3 ft with case vent closed and lid closed
Transducer Array:	Operating temperature -10°F to 100°F Maximum depth 130 ft (although limited to 75ft by cable length)

Applied Physical Sciences Corp.

Enhanced Underwater Loudhailer (eLOUD) Drawing Package 20-unit Prototype Design

Contract W91CRB-04-C-0057 CDRL A010

Bruce Abraham, PhD
Applied Physical Sciences Corp.
2 State Street, Suite 300
New London, CT 06320
Email: babraham@aphysci.com
Phone: 860-440-3253 x104

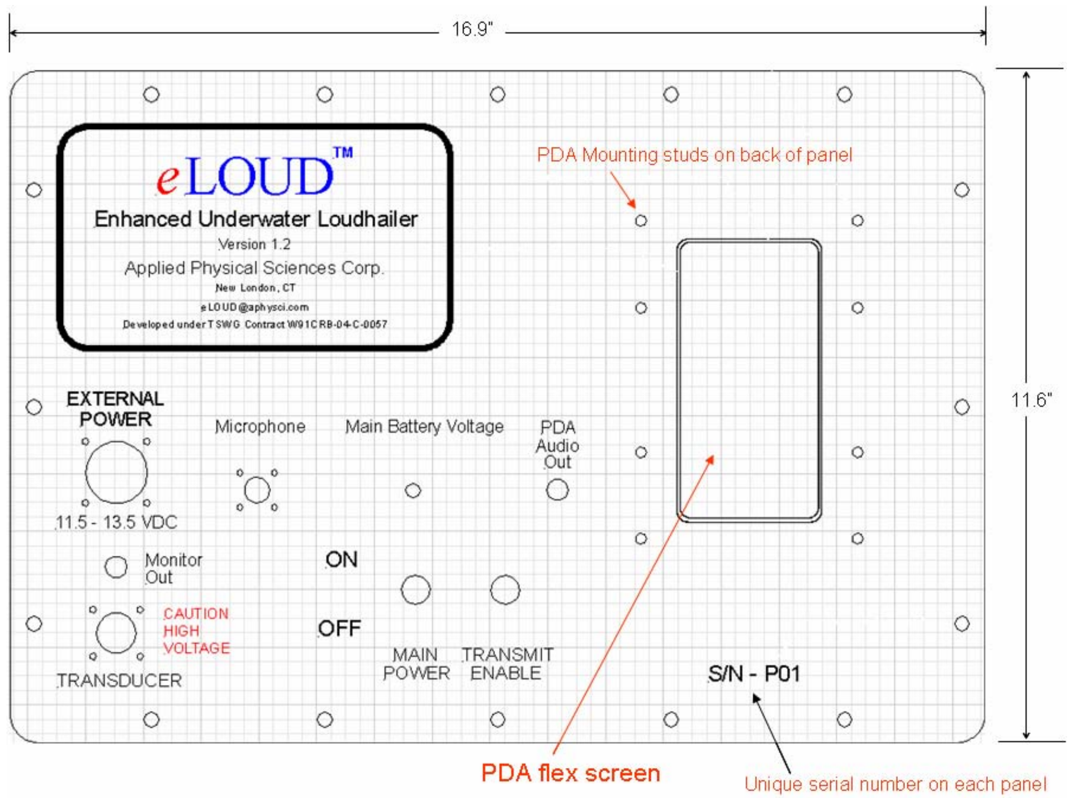
(2) Mechanical Drawings Schematics

(a) Loudhailer Front Panel

.eLOUD™ Front Panel

Bruce Abraham
Applied Physical Sciences Corp
2 State Street, Suite 300
New London, CT 06320
Phone 860-440-3253 x104
Fax 860-440-3075
Email babraham@aphysci.com
3 Nov 05

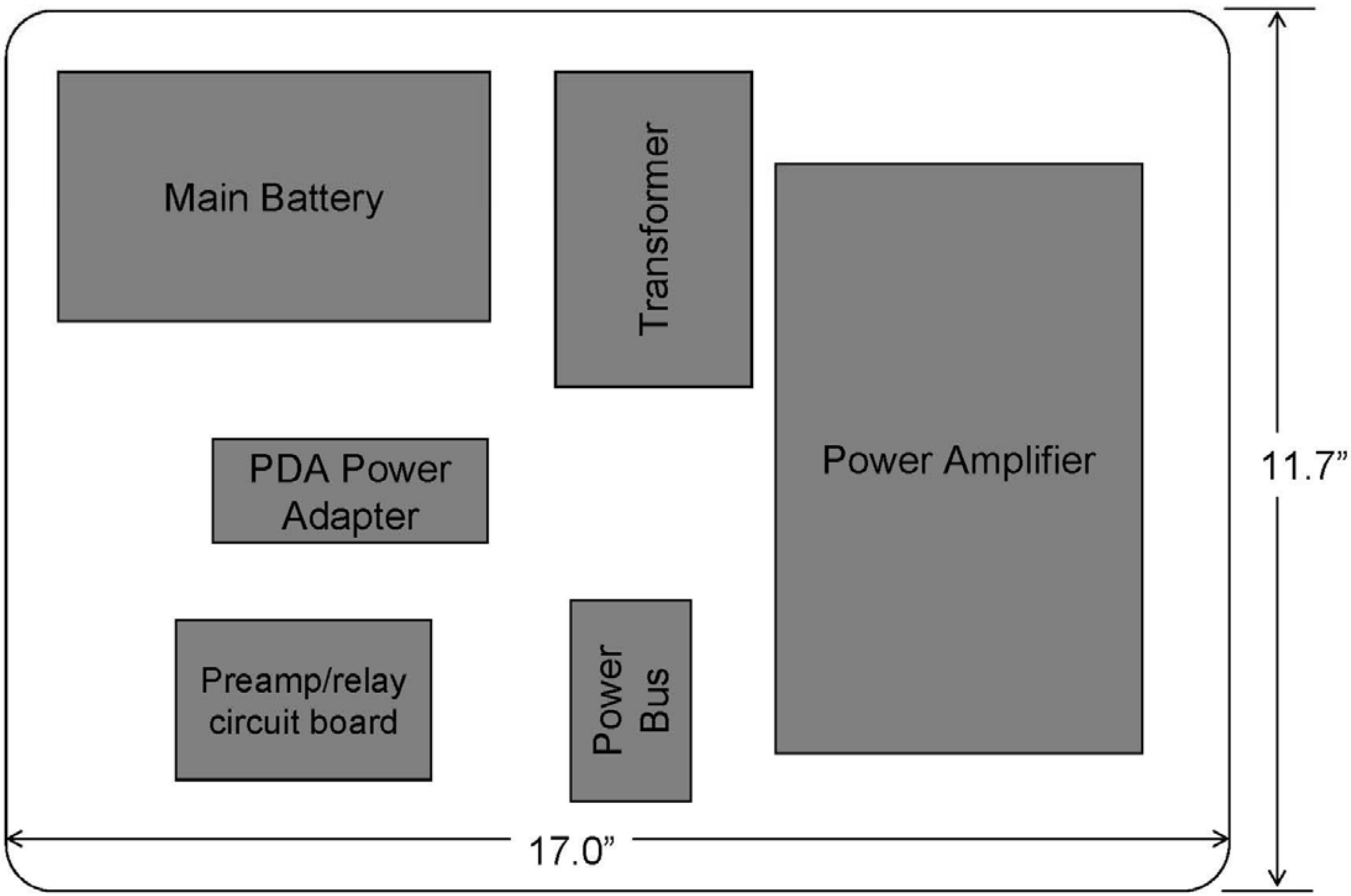
Tuf-Tex Laminate over 1/8” aluminum
Panel Color: Light Gray
Lettering: Black except:
“e” in large “eLOUD” is Navy Blue
Quantity: 20



(2) Mechanical Drawings Schematics

Applied Physical Sciences Corp.

(b) Control Unit Internal Component Layout

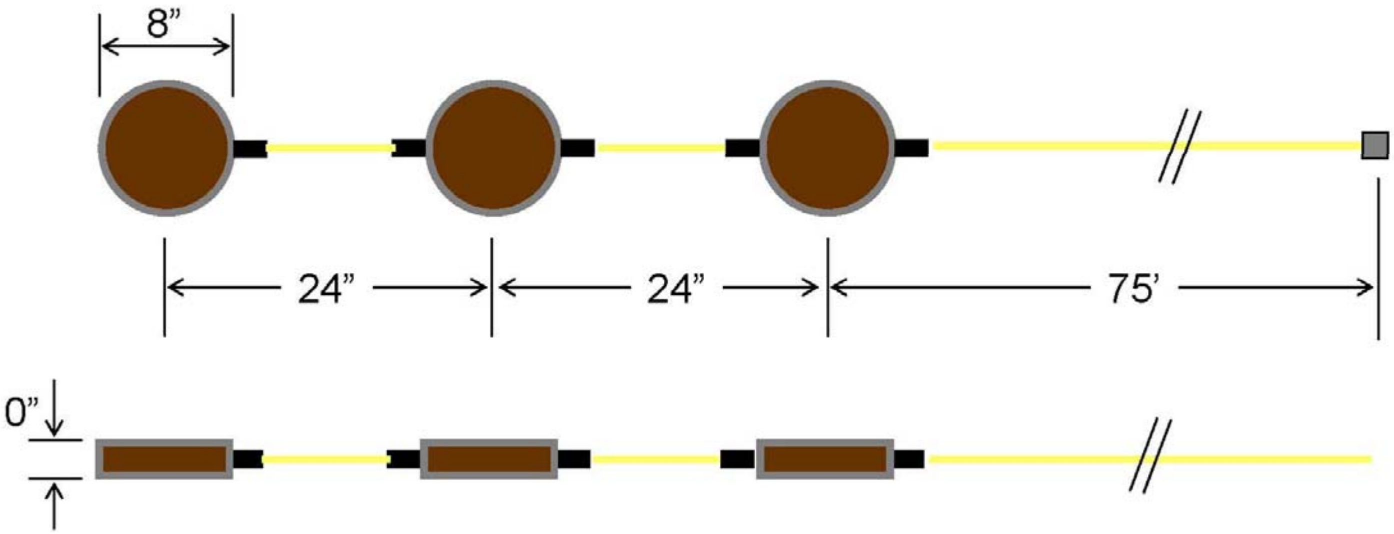


Not to scale

(2) Mechanical Drawings Schematics

(c) Transducer Array Dimensions

Applied Physical Sciences Corp.



Applied Physical Sciences Corp.

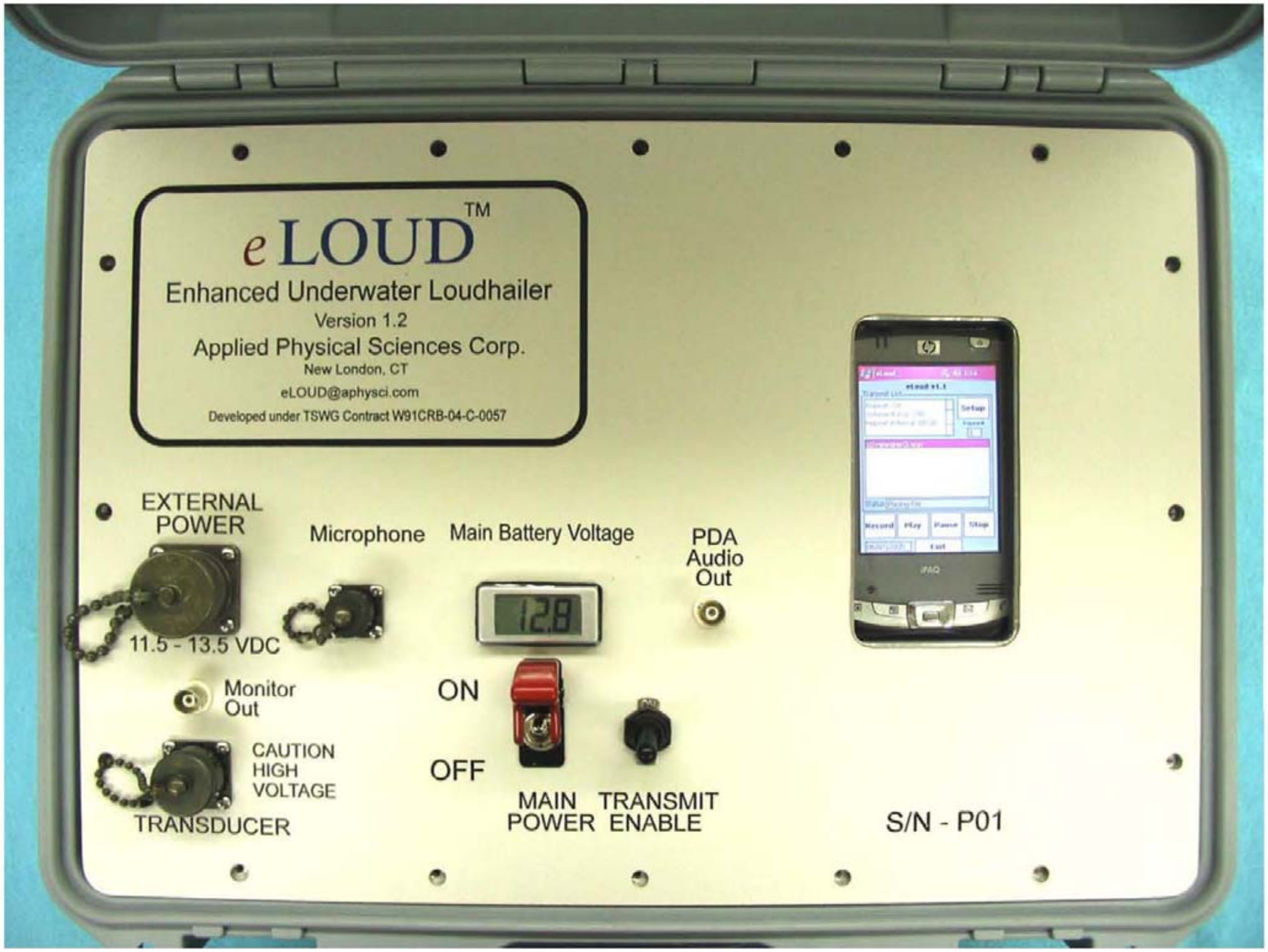
(3) Fabrication Pictures

(a) Control Unit Enclosure

(3) Fabrication Pictures

Applied Physical Sciences Corp.

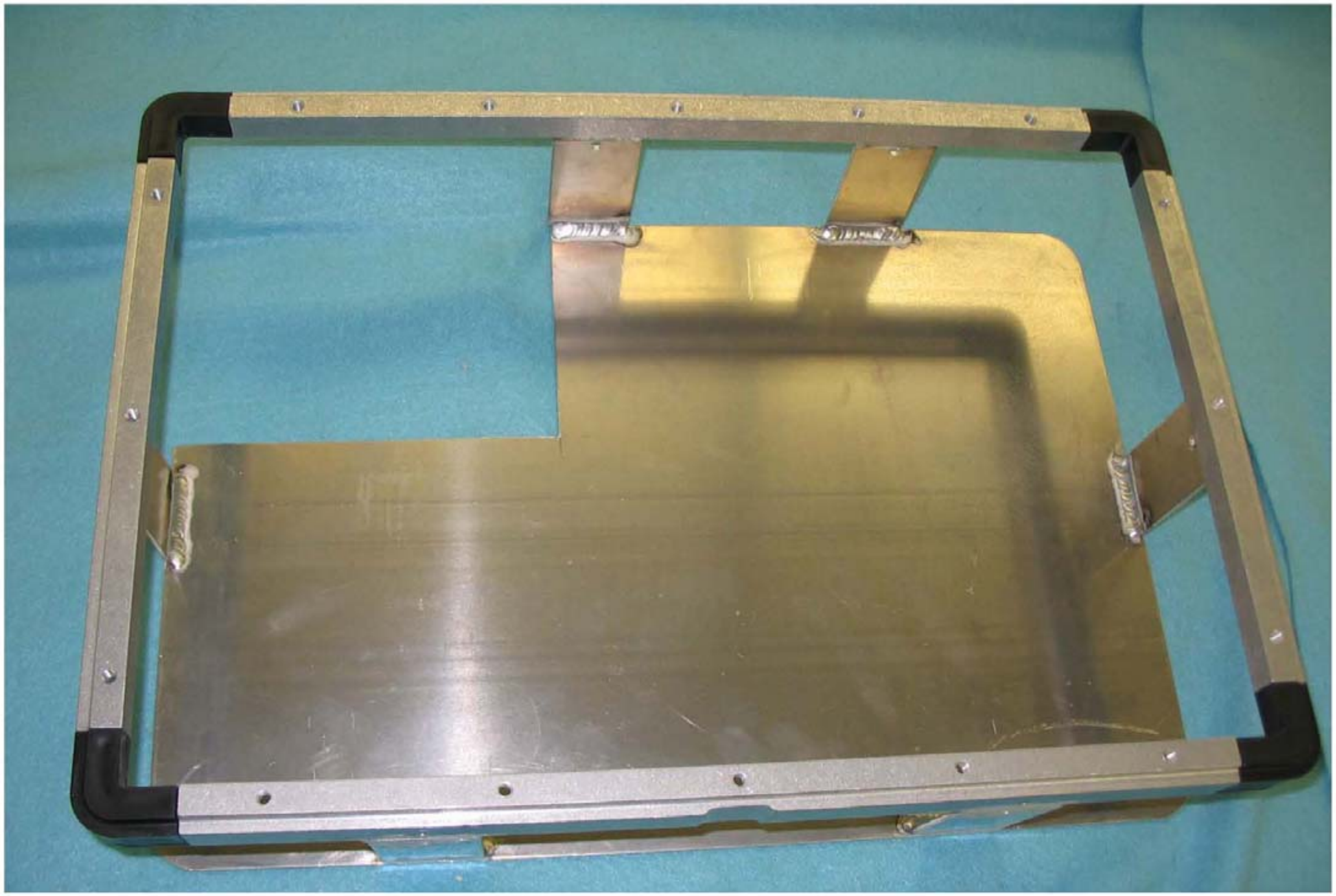
(b) Front Panel (Completed)



(3) Fabrication Pictures

(c) Control Unit Mounting Basket

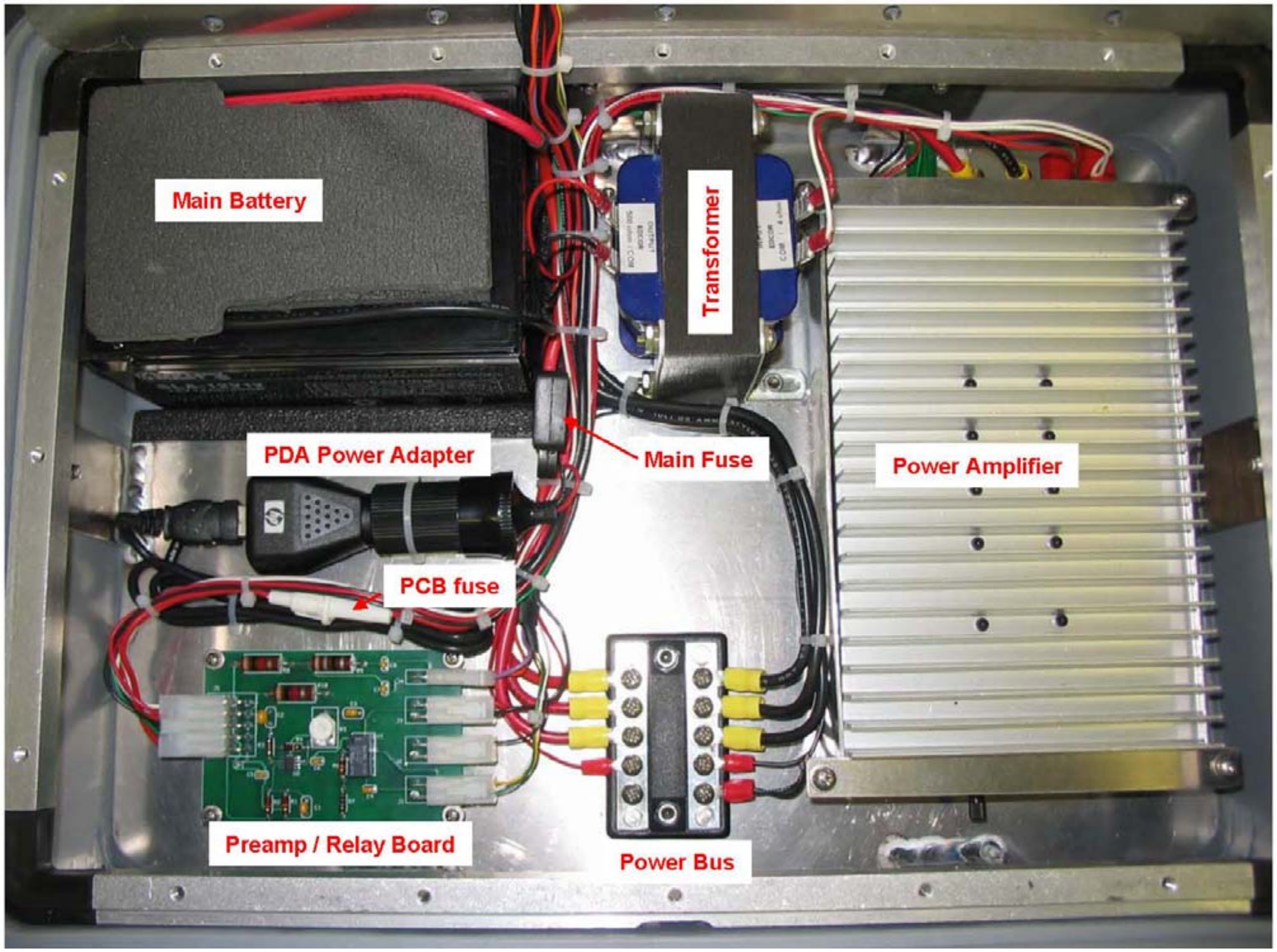
Applied Physical Sciences Corp.



(3) Fabrication Pictures

Applied Physical Sciences Corp.

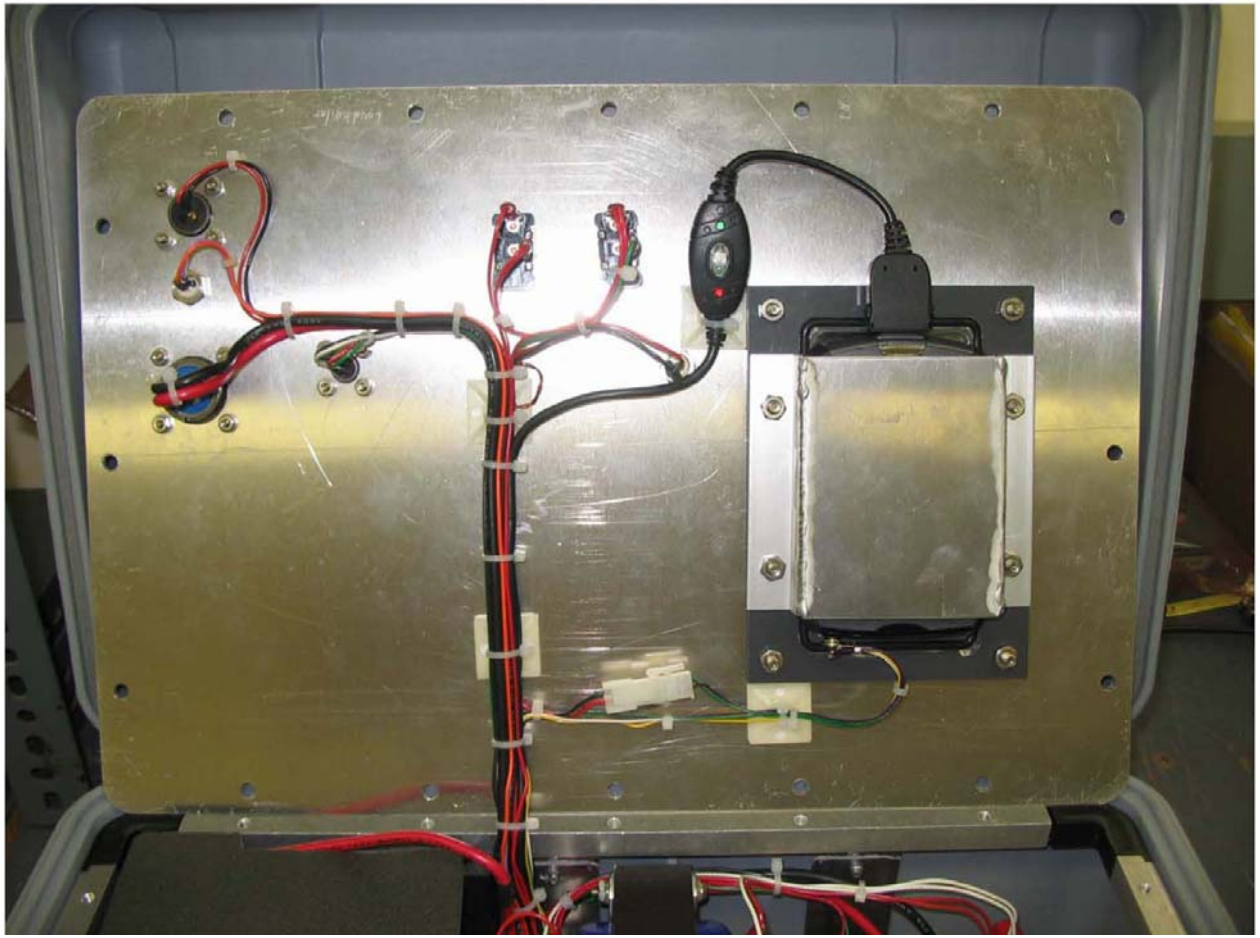
(d) Control Unit Internal Components



(3) Fabrication Pictures

Applied Physical Sciences Corp.

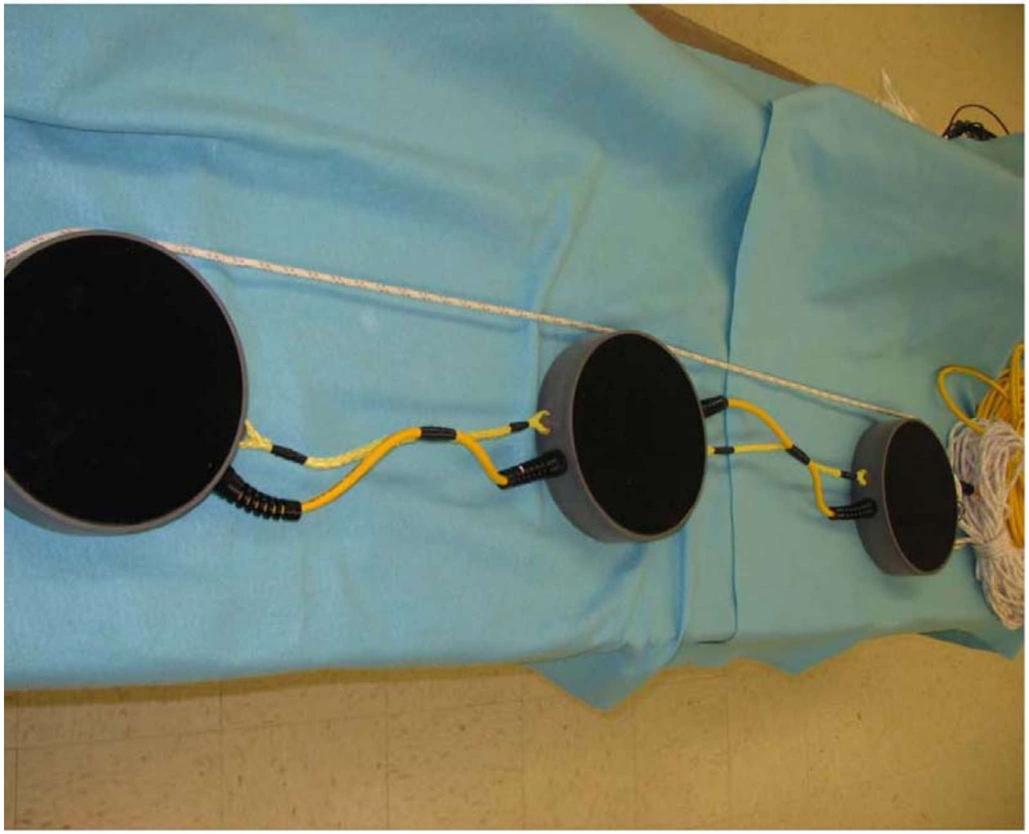
(e) Front Panel Wiring



(3) Fabrication Pictures

(f) Transducer Array

Applied Physical Sciences Corp.



APPENDIX F.
*e*LOUD™ USER MANUAL

Version 1.2

Applied Physical Sciences Corp.
2 State Street, Suit 300
New London, CT 06320
Phone: 860-440-3253 x104
Fax: 860-440-3075
Email: *e*LOUD@aphysci.com

Prepared under
TSWG Contract W91CRB-04-C-0057, CDRL A009

27 Dec 05

WARNINGS

- **The Enhanced Underwater Loudhailer (*e*LOUD™) is a high-power underwater audio transmission system that can cause permanent hearing loss and possibly more severe physiological damage if used incorrectly!**

- **NEVER use the system in a swimming pool or other enclosed area, even in air!**

- **NEVER use the system if a diver is less than 25 yards (22.5m) from the transmitters!**

- **NEVER use *e*LOUD™ with a damaged transducer cable or any other damaged components**

- **NEVER touch the "Transducer" connector pins on the front panel OR the connector on the transducer cable!**

Table of Contents

List of Figures

1. Introduction and System Overview

The *e*LOUD™ Enhanced Underwater Loudhailer is an underwater sound transmission system intended for use as a diver warning tool. It can transmit warning tones and voice messages to underwater listeners to ranges exceeding 500 yds. The unit is portable, relatively lightweight, battery-operated, and can be quickly deployed in an emergency situation. The system can transmit pre-recorded warning tones or messages or transmit live messages via a microphone. The main system components are:

- *e*LOUD™ Control Unit
- *e*LOUD™ Transducers
- *e*LOUD™ Accessories

This section will describe the function of the *e*LOUD™ components. The following sections of the User Manual will describe deployment and operation, precautions, maintenance procedures, troubleshooting and specifications.

The *e*LOUD™ system has three modes of operation:

(a) Transmit prerecorded messages
(b) Transmit live voice
(c) Record voice messages for subsequent storage and transmission

Figure F-1 shows a flowchart for operation of the *e*LOUD™ system. The primary mode of operation is for transmission of prerecorded messages. The user selects messages for playback and the integrated PDA generates audio signals which are amplified and sent to the underwater transducers. The user can configure which messages are transmitted, how many times they should be repeated, and how often to repeat the entire set of messages.

The second mode of operation is for live transmission of voice via the included microphone. After the unit is powered on, the user simply presses and holds the microphone switch to transmit voice messages.

The third mode of operation is for recording new messages onto the PDA. Custom recording and optimization software and the microphone are used for this function.

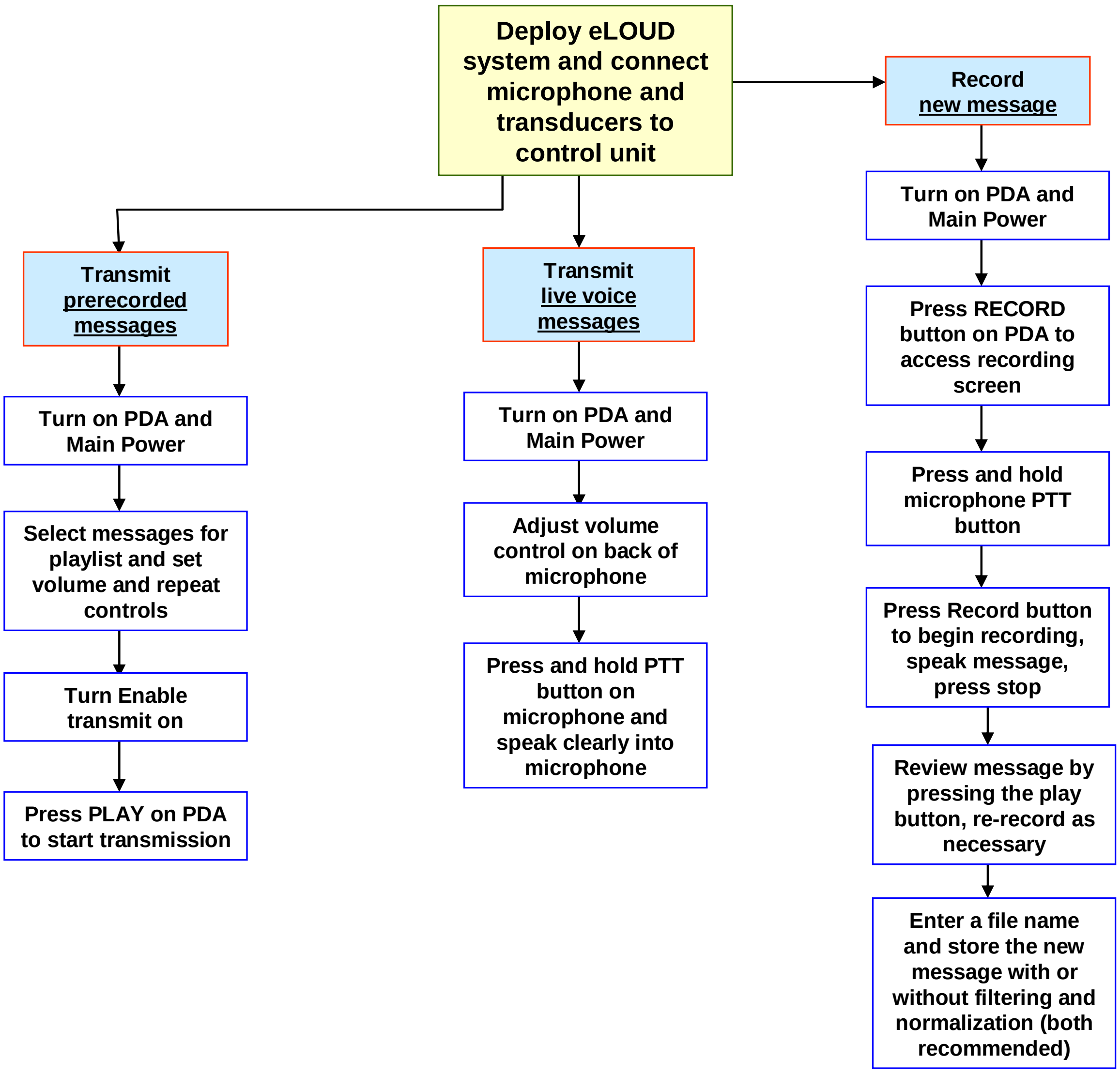


Figure F-1. *e*LOUD™ Operational Flowchart.

The *e*LOUD™ Control Unit shown in Figure F-2 contains all components required for operation except the underwater transducers and microphone. The Control Unit case houses the power amplifier, control PDA (computer), battery, switches, monitor outputs, and connectors. The Transducer case houses the transducer array, support line, spare parts, and microphone. The Control Unit case should normally be left closed and latched except during operation or charging. The Control Unit is splash-proof when open and waterproof to 3 ft submergence when closed.

Figure F-2. *e*LOUD™ Control Unit and Transducers Cases.

<u>IMPORTANT NOTE</u>: The manual vent near the handle should be left closed ("Seal" position) except during shipping or when significant atmospheric pressure changes are expected.

The *e*LOUD™ front panel shown in Figure F-3 contains all the connectors, switches, and other user interfaces required for operation. The control computer (HP iPAQ PDA) is mounted beneath a splash-proof, flexible, transparent membrane. The PDA buttons and touch screen are operated by pressing on the membrane itself. A stylus for the PDA is tethered to the front panel.

NOTE: Fingers, a capped pen, or other dull pointing device can be used in an emergency if the PDA stylus is missing. Press *gently* on the PDA screen.

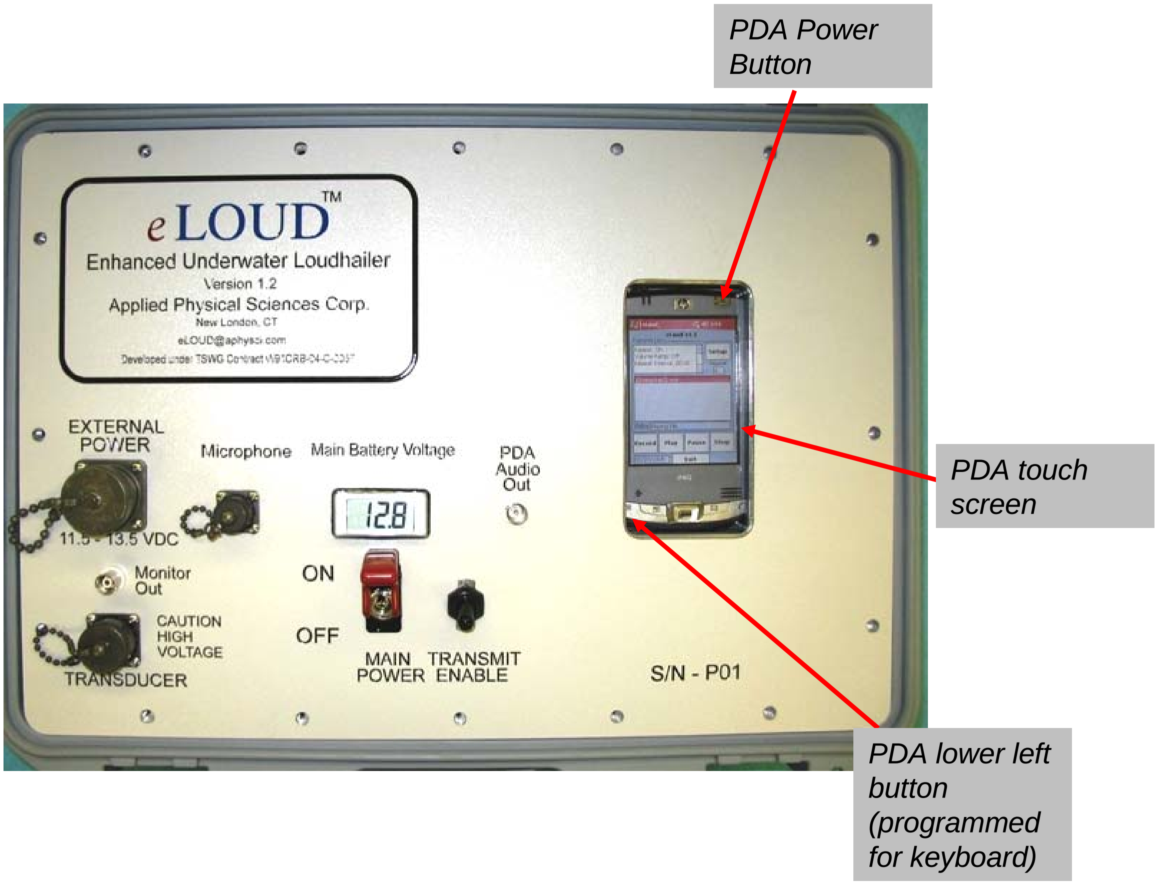


Figure F-3. *e*LOUD™ v1.2 Front Panel.

The *e*LOUD™ PDA runs custom software for playback and recording of warning messages and warning tones. When the main power is switched on the PDA should boot and automatically load the *e*LOUD™ control software. The user selects tones and/or messages to be transmitted via a pull-down menu and the set of messages and tones constitutes a playlist. The number of times a file or the entire playlist is repeated can be controlled by the user. Additionally the user can select an option to ramp-up the volume during successive playlist transmissions to allow close-in (< 25 yd) divers to surface without being harmed by the high sound pressure levels generated by *e*LOUD™. The control software's operation will be detailed in the next section.

The two main switches on the front panel are the Main Power and Transmit Enable switches. The Main Power switch turns power on to the PDA and microphone circuit. The Transmit Enable switch turns on the power amplifier.

IMPORTANT NOTE: The Main Power and Transmit Enable switches must both be **ON** to transmit messages underwater.

If the *e*LOUD™ control unit is being used to record new messages, then only the Main Power switch should be on.

Also on the front panel are three Amphenol® connectors and are clearly labeled. The largest connector is for 12 VDC power. Either the AC power charger cable or a direct battery cable can be attached to the External Power connector. The second largest connector is for the underwater transducers cable (yellow cable). The smallest connector is for the microphone. Connector covers should remain attached except during operation or charging.

IMPORTANT NOTE: When the *e*LOUD™ power amplifier is enabled and transmitting, the voltage at the transducer connector can be in excess of 500V. Never touch the connector sockets with any part of your body or a foreign object**.**

The remaining items on the front panel include an LCD battery voltage meter and two BNC audio jacks. One BNC jack provides an audio reference output from the right PDA audio output (PDA Monitor). This is same signal that is transmitted to the power amplifier and can be monitored with headphones or a small powered speaker (provided). This output should be used during recording operations to check the recorded message without having to enable the power amplifier. The second BNC jack provides a reduced version of the signal going directly to the transducers (Monitor Output). This output is the primary output for monitoring and can be attached to audio headphones or a small speaker. Both BNC outputs are monaural (mono). A BNC-to-RCA adapter and RCA-to-1/8" audio jack connectors are provided in the spare parts case.

This User Manual is stored in a pouch inside the Control Unit lid. Spare fuses and connectors are located in a box mounted in the Transducer Case. A synopsis of user operation and available default messages and sirens is posted inside the Control Unit case on a laminated quick-reference card.

The *e*LOUD™ underwater transducers, shown in Figure F-4, are the underwater "speakers" of the system. The transducers are normally stored in the larger of the two cases shown in Figure F-2. The transducer array should be suspended vertically from the deployment area (e.g. boat, pier, barge, etc). Three transducers are used to focus the sound along the horizontal plane for better transmission to underwater listeners. A 10-15 lb ballast weight (not included) is typically used to keep the transducer array vertical in the presence of small currents.

IMPORTANT NOTE: This array is intended for pier, drifting, anchored, or moored platforms should never be deployed from a vessel that is underway.

The angle of the array with respect to the vertical should not exceed 15^{o} for proper operation.

Figure F-4. *e*LOUD™ Underwater Transducers.

The *e*LOUD™ speakers contain piezoelectric elements and therefore require a high drive voltage to transmit significant levels of sound. A step-up transformer in the Control Unit provides 500+ volts (AC) to the transducers in the frequency band 400 – 3500 Hz. The transducers have damped resonances at 500 and 2700 Hz and maximum power is transmitted around these frequencies. The *e*LOUD™ system was designed to transmit tones and messages to divers wearing neoprene headgear which can significantly attenuate sound above 700 Hz frequency. The nominal high/low *e*LOUD™ warning siren (siren1.wav) was designed to drive the transducers at maximum power and to effectively transmit these sounds to divers.

The maximum measured Sound Pressure Level (SPL) in decibels (dB) referenced to 1 μPa at 1m distance is shown in Figure F-5. This represents the maximum sound power that the system can generate as a function of frequency. The maximum un-weighted SPL (i.e. not A- or C-weighted) is in excess of 190 dB at 1m distance. The user can estimate the maximum receive level by reducing the levels in Figure F-5 by $20\log_{10}(R)$ decibels where R is the range in meters.

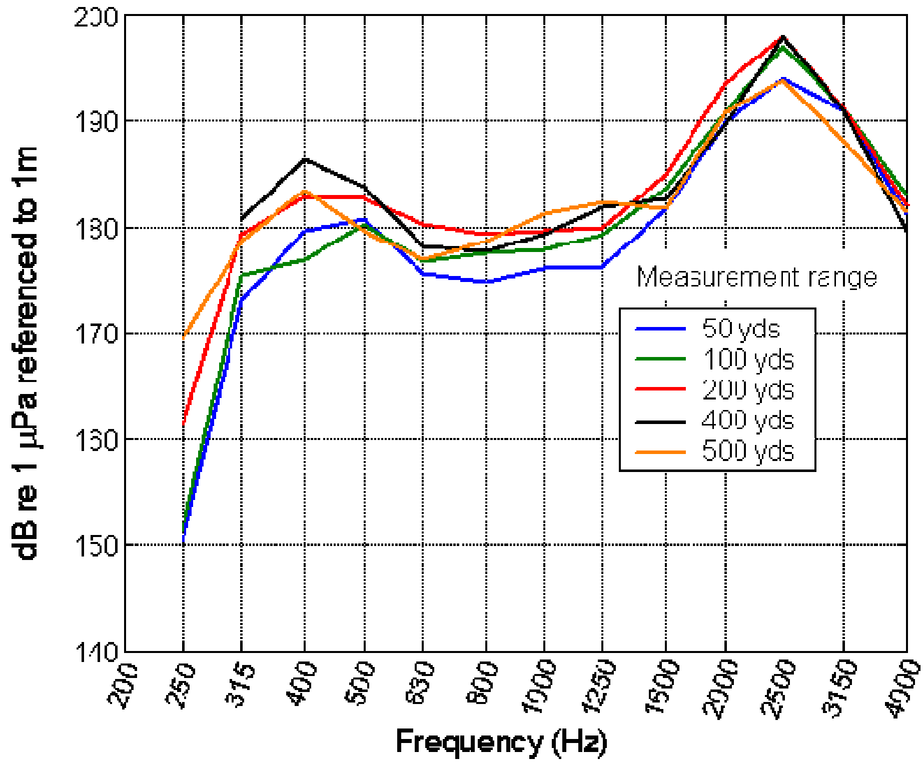


Figure F-5. Measured Maximum Sound Level from *e*LOUD™ System.

(Note measurements made at noted distance and corrected to 1m range using spherical spreading. Estimate receive level by decreasing by $20\log_{10}R$ where R is in meters)

2. Deployment and Operation

The *e*LOUD™ deployment and operation is straightforward and can be performed by one person in the field. The primary steps include:

- Retrieve system from storage/maintenance area
- Transport system to pier, vessel, or other deployment platform
- Deploy transducer array at operational area (OPAREA)
- Operate Control Unit

After operation, the following steps are recommended:

- Retrieve transducer array
- Wash down transducers and cable
- Stow transducer array
- Stow Control Unit and connection to battery charger

2.1 Retrieve *e*LOUD™ System from Storage/Maintenance Area

The battery charging cable should be disconnected from the *e*LOUD™ system. Turn on the Main Power switch on the Front Panel and verify the battery voltage is higher than 12V (typically 12.3 to 12.8 VDC after charging). Both switches on the front panel should be in the OFF position. The Control Unit lid should be closed and latched. If AC operation is anticipated, then the charger should be packed inside the Control Unit lid. If direct DC (e.g boat 12V power) is anticipated, then the DC power cable should be packed in the Control Unit lid. See section 4.2 for battery replacement procedures. The unit should be connected to the battery charger during normal storage (standby).

> **IMPORTANT NOTE**: If the battery voltage is below 12V, either replace the internal battery with a fully-charged one or plan on powering the unit from external power at the operations area (OPAREA).

2.2 Transportation of *e*LOUD™ System to OPAREA

The Control Unit and Transducer cases should be carried or otherwise transported to the OPAREA. The cases are easily carried with one case in each hand. Care should be taken not to drop either case during transportation, especially the Control Unit. Although the Control Unit is rugged, it does contain electronic equipment and should be treated accordingly. The vent on the Control Unit should be in the “Seal” or closed position.

2.3 Deploy transducer array at OPAREA

Open the transducer case and lay out the transducers, cable, and suspension line (rope) on the deck. Attach a 10 to 15 lb ballast weight to the 5-ft piece of line coming off the bottom-most transducer (the one with only one cable penetration). The weight should be relatively small and at least 2 ft away from the transducer to prevent acoustic interference. Diver weights serve well in this function. Do not use air-filled ballast as this could cause unwanted acoustic reflections and distortion.

Lower the ballast weight and transducers into the water while keeping tension on the suspension line. Lower the transducer array to half the nominal water depth. Markings on the transducer cable have the depth noted every 5 ft from 10 to 55 ft.

> **IMPORTANT NOTE:** Never suspend the transducer array from the electrical cable. Always use the included line or one rated for at least 100 lb breaking strength.

2.4 Operate Control Unit

Open the *e*LOUD™ Control Unit lid and verify the Main Power and Transmit Enable switches are OFF. Connect the transducer cable to the transducer bulkhead connector on the front panel. Turn the Main Power switch on and the PDA will reboot and load the *e*LOUD™ control software. After the PDA software has loaded, turn the Transmit Enable switch ON. A default playlist will be displayed if the required audio files are present on the Secure Digital™ (SD) removable data card. Operation of the *e*LOUD™ control software will be described next.

2.4.1 *e*LOUD™ Control Software Operation

Sound is transmitted by the *e*LOUD™ system either by talking into the microphone with the push-to-talk (PTT) button depressed or by playing sound files from the PDA. Typical operation involves playing one or more warning tones and messages from the PDA. The *e*LOUD™ control software has three main screens:

- Main (Playback) Screen
- Playlist Setup Screen
- Recording Screen

The Main screen is the screen shown upon startup of the *e*LOUD™ software and is shown in Figure F-6. The white box in the upper-left part of the screen contains playback parameters for the playlist including:

- Repeat: On or Off (tells whether playlist will be repeated or not)
- Volume Ramp: On or Off (tells when playlist volume will be ramped up in three increments on successive playlist repetitions. Default is off)
- Repeat Interval: MM:SS (MM is minutes, SS is seconds, defines time to pause between repeating the playlist, e.g. 05:35 denotes waiting 5 minutes, 35 seconds)

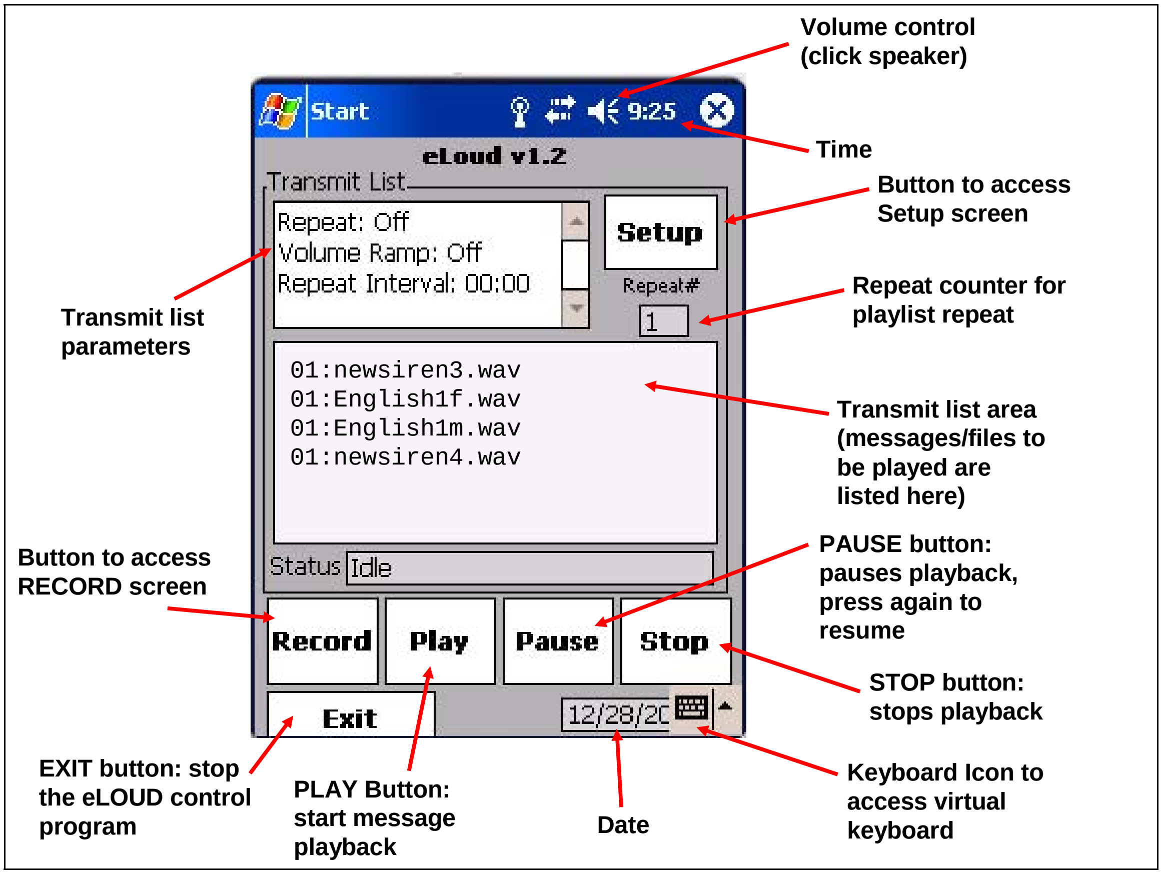


Figure F-6. *e*LOUD™ Control Software Main Screen.

The large white box in the middle of the Main Screen displays a list of message file names that will be transmitted (refer to the reference card inside the Control Unit lid for the text of each message). The number preceding each file name is the number of times that file will be repeated during the playlist playback.

There are six virtual "buttons" on the Main Screen. These include Setup, Record, Play, Pause, Stop, and Exit. The functions of these buttons are as follows:

- Setup: Enter the Setup screen where the playlist can be modified and/or defined from scratch
- Record: Enter the Record screen where messages can be recorded using the microphone and stored to the PDA SD card for future playback
- Play: Start playing the playlist
- Pause: Pause the playback. Pressing again resumes playback
- Stop: Stops playback. When play is started again, the playback begins with the first file of the playlist
- Exit: Quit the *e*LOUD™ control software and return to Windows Mobile 2003 operating system

2.4.2 Creating a Default Playlist

The default playlist can be defined by editing the "default.txt" text file in the \\SD\Loudhailer directory. The file format is as follows:

VOLUMERAMP:**ON** or **OFF**
REPEAT:**ON** or **OFF**
DELAY:Integer number of seconds (e.g. 5)
XX:File1 (XX is number of repeats for File1, File1 is filename without *.wav extension)
YY:File2 (second file in playlist)
ZZ:File3 (third file in playlist)
(etc.)

Note the filenames are case-sensitive. An example of a default playlist setup file is as follows:

VOLUMERAMP:OFF
REPEAT:ON
DELAY:0
1:newsiren3
1:English1f
1:English1m
1:newsiren4

The default.txt file can be edited on the PDA using the Windows Mobile 5.0 software or by inserting the SD card into a PC with an appropriate card reader.

2.4.3 Modifying or Creating an *e*LOUD™ Playlist

To modify or create a playlist, press the Setup button. The Setup screen will appear as shown in Figure F-7. The current playlist files are listed in the main window in the center of the screen. The order of playback is indicated by the order of the files in the list. The pull-down menu at the top (press the triangle with the stylus) provides a list of all *.wav files in the \\SD\Loudhailer directory on the SD card. To add a file to the playlist, select it and press the Add button. To replace a file, first select it from the playlist by clicking (pointing) once on it then select a different file from the pull-down menu and press the Replace button. To delete a file from the playlist, select it and press the Delete button.

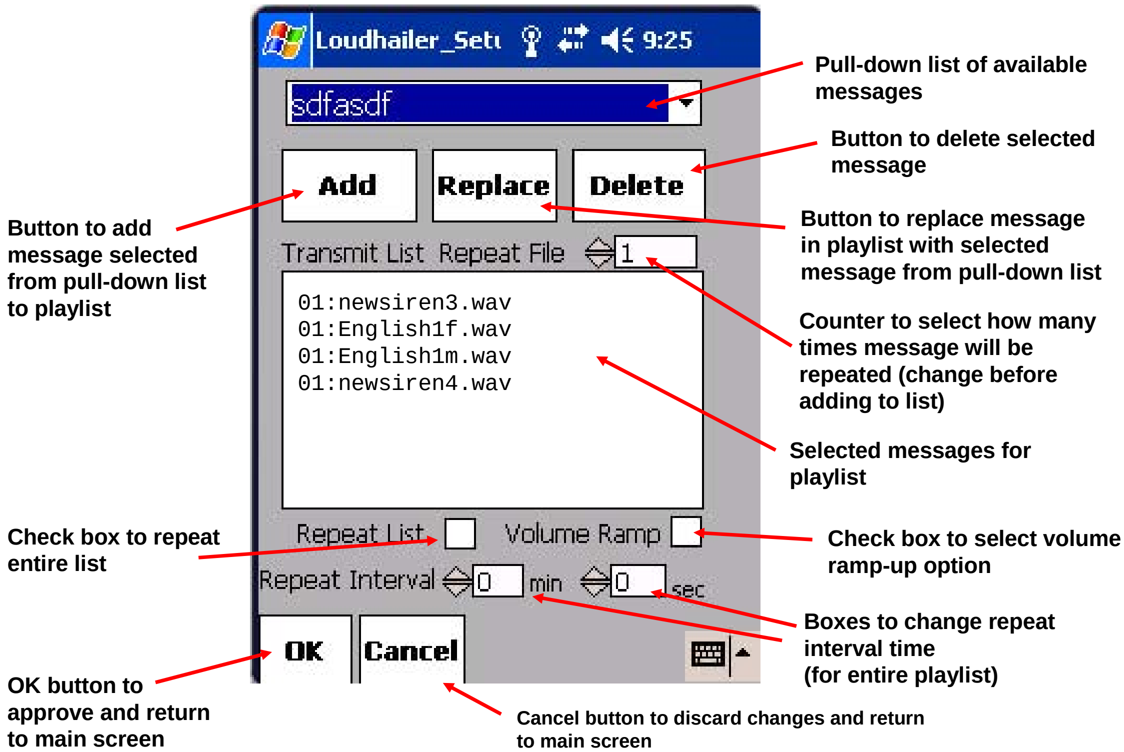


Figure F-7. *e*LOUD™ Control Software Setup Screen.

A file can be repeated a number of times during playback. To specify this, select a file from the pull-down list, select the number of repetitions by clicking the up and down arrows on the "Repeat File" indicator then press the Add button. When multiple files are selected, the first will be repeated the selected number of times then the second, etc.

There are two checkboxes below the transmit file list. The "Repeat List" box when checked will repeat the entire playlist pausing the specified time in the "Repeat Interval" control. The "Volume Ramp" box, when checked, will playback the entire playlist in the following manner:

- First time transmitting playlist at 33% volume
- Second time transmitting playlist at 66% volume
- Third and subsequent times transmitting playlist at 100% volume

When modifications to the playlist are complete, press the OK button or press the Cancel button to discard the changes and return to the Main screen.

2.4.4 Recording a New Message for *e*LOUD™

The Record button on the Main screen will access the Recording screen as shown in Figure F-8. This screen allows the user to record, check, and store new message files for future playback. The recorded messages can be band-pass filtered and normalized to optimize them for playback on the *e*LOUD™ system. The recording procedure is as follows:

1. Turn the Main Power button on the front panel on but leave the Transmit Enable button off. Connect the microphone to the front panel.
2. Press and hold the microphone PTT button.
3. Press the PDA Record button and clearly speak the message towards the PDA (not the external microphone; see note below). Do not shout the message. Press the Stop button when finished *before* releasing the microphone PTT button.
4. Press the Play button to listen to the recorded message. To hear the message, connect headphones or a small speaker to the PDA Monitor BNC jack on the front panel. *Alternatively*, simply hold the microphone PTT button and the message will be played back on the PDA internal microphone.

IMPORTANT NOTE: Version 1.2 of the *e*LOUD™ system uses the internal PDA microphone but this is enabled by pressing the push-button on the external microphone (do not speak into the external microphone when recording; speak close to the PDA itself).

IMPORTANT NOTE: Speak clearly and slowly when recording messages. Use good diction and never slur words. Divers have reported that female voices are generally easier to hear so consider using a female speaker if possible for maximum effectiveness.

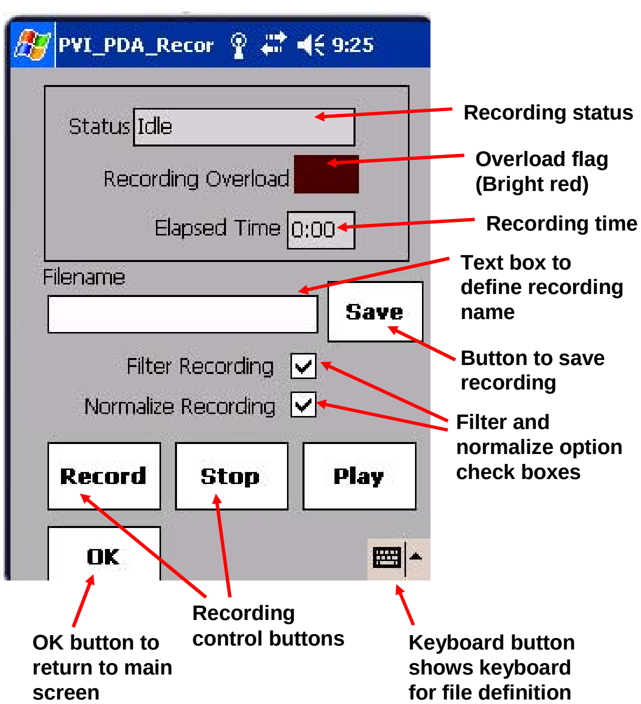


Figure F-8. *e*LOUD™ Control Software Recording Screen.

5. Re-record and re-play the message as needed. If the Recording overload indicator illuminates, this is okay as the automatic gain control for the microphone will trip this. If desired the user can set the microphone gain to a fixed value via the System/iPAQ Audio control panel. The maximum recording length is 60 seconds per message. Approximately 180 message of 60-second duration will fit on the 256 MB SD storage card.
6. When the message is satisfactory, select the “Filter Recording” and “Normalize Recording” check boxes. The Filter option will band-pass filter the message in the frequency band 400 – 4000 Hz which is the *e*LOUD™ operating band. The system is not designed to transmit audio messages with frequency content above 4000 Hz (e.g. music). The Normalize function will automatically adjust the volume of the message so that it will be transmitted as loud as possible. Both the Filter and Normalize functions are recommended for default operation.
7. Click in the “Filename” box then press the small keyboard icon in the lower-right corner. A virtual keyboard will appear. Enter a file name (without the *.wav extension). <u>Do not</u> press the ↵ (Enter) key on the virtual keyboard. Simply close the keyboard by pressing the keyboard icon again. Check the file name and if satisfactory press the <u>Save</u> button. The message is stored in the \\SD\Loudhailer directory on the SD card with the specified file name with “.wav” appended. Note this function may take up to 30 seconds for a long recording.
8. Click the <u>OK</u> button to return to the Main screen. The new message is available for playback via the Setup screen. You may want to annotate the reference card with your new messages. Messages are listed including the “*.wav” file suffix.

2.4.4 Live Voice Transmission

The *e*LOUD™ system can be used to transmit live voice messages via the included microphone. Attach the microphone to the “microphone” connector on the Front Panel. Turn both the <u>Main Power</u> and <u>Transmit Enable</u> switches on. Push and hold the button on the microphone and speak (not shout) clearly and slowly into the microphone. Release the button when finished speaking. There is a volume control knob on the back of the microphone. Rotate the knob fully clockwise for maximum volume.

IMPORTANT NOTE: If the user yells extremely loudly or blows strongly on the microphone there is a small chance that the power amplifier will enter “protection” mode and underwater audio transmissions will stop. Reset the amplifier by turning the transmit enable switch off for 5 seconds then turning it back on. The user can monitor the signal via the Monitor Out audio jack.

2.4.4 *e*LOUD™ Control Software Notes

- If the keyboard icon is not shown on the screen, press the lower left PDA button (real, not virtual button) to access the keyboard. Press it again to hide the keyboard. This option

was programmed in the PDA by APS and will have to be reprogrammed if the PDA loses power.

- See the "PDA Setup" section for instructions on setting up the PDA from a complete memory loss situation
- The files in the \\SD\Loudhailer directory can be edited (e.g. copied/deleted) by using a PC with an SD card reader or using the Windows Mobile 5.0 operating system on the PDA. The easiest way to install wave files on the SD card is to use a separate PC and copy the files using Windows Explorer. Theoretically the PDA can be connected to a PC using a USB cable but this is not recommended.

2.5 Message and Warning Tone Playback

When a satisfactory playlist has been programmed, check the PDA volume level by clicking the small speaker icon in the upper right corner of the screen (refer to Figure F-6). For normal operation the volume would be set to maximum. Pressing the Play button will begin audio transmission if the Main Power and Transmit Enable buttons are on and the transducer array is connected.

IMPORTANT NOTE: Do not transmit at maximum volume if divers are within 25 yds of the transducer array!

It is normal for the main battery voltage to drop during audio transmission as significant current is being drawn out of the battery. When the "idle" battery voltage drops below 11V, either replace the battery or connect to an external power source (AC adapter or direct DC power). Do not connect to direct DC power if the battery voltage is less than 10.5V because battery overheating can occur (the battery will be charged at too high a rate).

2.6 *e*LOUD™ Shutdown and Stowage Procedures

- Turn the Main Power and Transmit Enable buttons off. Press the Exit button on the *e*LOUD™ control software Main screen. Turn off the PDA by pressing the PDA power button.
- Disconnect the transducer cable and microphone cable (if connected)
- Attach the connector covers and close and latch the Control Unit lid
- Retrieve the transducer array and disconnect the ballast weight
- Wash down the transducer array and support line with clean, fresh water and let air-dry.
- Sponge-off the Control Unit front panel and both storage cases if exposed to salt water
- Stow the transducer array in its case along with the transducer cable and support line.
- For normal "standby" storage, connect the AC battery charger to the *e*LOUD™ Control Unit and store in a clean, dry place
- For extended storage, refer to the Maintenance section.

3.0 Precautions

The eLOUD™ system is a high power underwater audio system and misuse can cause severe physiological damage to underwater listeners.

- Inspect all cables for nicks and cuts. Repair or replace damaged cables as needed.
- The voltage at the transducer connect on the *e*LOUD™ front panel can exceed 500V. Never short, ground, or otherwise connect anything except the transducer array connector to the transducer bulkhead connector. Keep the connector caps secured on the Control Unit when not in use.
- Never listen to the transducer array by placing your head in the water near the array.
- All divers, suspected divers, or marine mammals should be at least 25 yards from the transducer array during *e*LOUD™ operation.
- Do not operate the *e*LOUD™ system with the transducers out of the water except at the lowest volume setting. Operating the transducers at full power in air can be potentially harmful to the listener and could damage the transducers.
- Keep the manual vent on the Control Unit case closed at all times except during air-shipping or when significant atmospheric pressure changes are expected. Water can directly enter the vent when open.
- Never suspend the transducer array by its electrical cable. Always use a separate suspension line connected to the nylon harness on the topmost transducer.
- Do not connect the battery to direct 12 V DC power (e.g. ship power) if the main battery voltage is less than 10.5 V DC. Overheating can occur. Use the supplied battery charger instead.

4. Charging and Maintenance Procedures

Maintenance and charging of the *e*LOUD™ system is straightforward. First routine maintenance will be described then long-term storage procedures will be discussed.

4.1 Routine Maintenance and Charging Procedures

Transducer Array:

- Check the array for obvious damage on a monthly basis and before deployment
- The black compression gland seals on the transducers should be tightened with a wrench just past hand-tight to prevent water entry into the transducers
- The connector should be inspected and replaced if the shell or pins are damaged
- The cable should be replaced if the jacket or conductors are cut or damaged in any way
- The transducers, nylon harnesses, cable, and suspension line should be rinsed and dried after each use

Control Unit:

- Connect the battery charger to an AC outlet and to the *e*LOUD™ "External Power" front panel connector. The red 12V light on the charger should illuminate.
- The Main Power and Transmit Enable switches should be in the OFF during storage. The PDA has non-volatile flash memory and does not have a battery installed. Therefore charging of the PDA is not required.

IMPORTANT NOTE: Leave the AC battery charger connected to the Control Unit during normal storage (standby)

- Check the PDA flexible screen cover for cuts and holes. Replace as necessary (refer to section 7.5 for parts).
- Check connectors, switches, and the battery voltage meter for damage and repair as necessary
- If the battery will not charge to at least 12.2V (voltage with charger disconnected), replace it with a 12V, 12Ah, sealed lead acid battery (refer to section 7.5 for parts)

Storage Cases:

- Keep the storage cases clean and rinse the outer covers as needed
- Keep the manual vent on the Control Unit case closed at all times except during air shipping or when significant atmospheric pressure changes are expected. Water can directly enter the vent when open.

4.2 Long-Term Storage Procedures

If the *e*LOUD™ system needs to be stored for a long period of time, the following procedures are recommended:

- Remove the front panel by removing the Phillips-head screws and remove the connectors from the main battery. Place electrical tape over the battery terminals.
- Close lid without latching so as not to deform the front panel o-ring seal.

After long-term storage, the following procedures are recommended:

- Install and recharge the battery. Replace the battery if it will not hold a charge.
- Turn the main power switch on and check the PDA operation. Re-load the *e*LOUD™ software if necessary (See section 6).
- Check connectors and other components for tightness and overall condition. Repair as necessary

5. Troubleshooting

Problem	Possible Cause and Suggested Action
Battery meter reads "Lo" or nothing when Main Power switch is on	Voltage is not reaching the meter. Charge main battery. If necessary, open front panel by removing screws and check connections to main battery. Replace battery if it will not charge. Check the 20A main fuse and replace if necessary.
PDA will not turn on	PDA is not receiving power. Turn the Main Power switch on. If the PDA does not start, open the control unit and check the fuse on the 12V cigarette lighter power adapter for the PDA. Replace if necessary.
eLOUD not transmitting sound	Make sure that transducer cable is securely connected. Make sure Main Power and Transmit Enable switches are ON. Check that volume level (speaker icon) on PDA is set at maximum. If necessary, open the front panel and check the 20A fuse. Check for sound on both BNC monitor jacks. If sound is reaching amplifer but is not reaching transducers, then transformer or amplifier may be damaged.
PDA screen hard to read	Set the backlight brightness and contrast to maximum using the PDA System settings control panel. In direct sunlight, try shading the screen or viewing the screen at different angles.
PDA Software not loading	Using the File Explorer, navigate to the \\SD\Loudhailer directory and start the **eLoud** program. When convenient follow procedures for PDA setup.
Sound is not heard from the transducers even though Transmit Enable and Main Power are on and PDA is playing messages	1. Cycle Transmit Enable Switch on and off. If that solves problem, then amp fault circuit was tripped (try lowering the volume). Verify audio output from PDA using PDA Audio Out jack. 2. Verify signal from Monitor out jack. If there is no signal, then amp is not working. Toggle Transmit Enable switch on and off and if that doesn't work check internal 20A fuse.
Keyboard icon is not present	Press the lower left PDA button (looks like a calendar) and the keyboard will appear. Press the same button to close the keyboard screen.

6. PDA Setup Procedures

6.1 Procedure for Loading Message Files on Secure Digital Card

- Open the *e*LOUD™ Control Unit lid and remove the screws from the front panel.
- Tilt up the front panel and locate the top of the PDA where the SD card is installed.
- Press the SD card once and it will pop up. Carefully remove the card and do not touch the gold conductors on the bottom of the card.
- Insert the SD card into an SD card reader connected to a PC.
- Copy messages (wave files) to the \\Loudhailer directory on the SD card. Note the wave files must conform to the format noted in the Specifications section (16 bit, mono, 11025 Hz sample rate).
- The provided SD card has at least 256 MB of memory available. Over 180, one-minute messages can be installed on a single card.
- When messages have been copied, return the SD card to the PDA, re-attach the front panel, and operate the *e*LOUD™ control software to verify the new messages are available and play properly.

6.2 Procedure for Resetting PDA System Settings

If the PDA has to be replaced with a new one or if for some reason the system has lost its settings, follow these procedures:

- Turn the Main Power switch on and the PDA should turn on
- Follow the Windows Mobile 5.0 on-screen instructions for aligning the screen and the brief tutorial
- Set the time zone and follow the on-screen instructions
- From the Start Menu (click upper left corner of screen), select *Settings*
    - Select the *Sounds and Notifications* icon. Uncheck all boxes. This will disable standard system sounds which would otherwise be transmitted into the water. Click the OK button in the upper right corner.
    - Select the System Tab then Backlight. Click the External Power tab. Make sure the "Turn off backlight if device is not used" box is unchecked. Click the Brightness tab and set both brightness levels to maximum. Click the OK button in the upper right corner.
    - Select the "X" button in the upper right corner to close the window
    - Select the Power icon then the "Advanced" tab. Under "On Battery Power," make sure the check box under "On external Power:" is *not* selected.
- From the Start Menu, select Programs
    - Select *File Explorer*. Navigate to *My Device* then *SD Card* (the SD card needs to be installed). Select the *Loudhailer* directory. Find the *eLOUD* executable file. Click and hold on the file and select *Copy*.

- Navigate to the *My Device \ Windows \ Startup* folder. In the blank space just *below* the file listing, click and hold then select *Paste*. The eLOUD program will be copied to the folder. Delete all the other files in this directory by clicking and holding on each file and selecting *Delete*.
- Click and hold on the *eLOUD* file and select *Copy*.
- Navigate up to the *Windows* directory then to the *Start Menu\Programs* directory. In the blank space *just below* the file listing, click and hold then select *Paste*.
- Select the “X” button in the upper right corner to close the window

- From the Start Menu, select *Settings*
  - Select *Menus*
    - Uncheck all items except eLOUD and File Explorer
    - Click OK in the upper right corner to close the window
  - Select *Input* then the *Options* tab
    - Set the voice recording format at *11,025 Hz, 16 bit Mono (22 KB/s)*
    - Click OK in the upper right corner to close the window
  - Select Buttons
    - Assign Button 1 to “<Input Panel>” using the pull-down menu near the bottom of the screen. This will program the lower-left button to pop-up the virtual keyboard when pressed.
    - Click OK in the upper right corner to close the window
- Cycle the Main Power switch off then on. After approximately 25 seconds the PDA will reboot and the eLOUD software will automatically load.

7. eLOUD™ Specifications

7.1 Electrical

Battery:	12V, 12Ah sealed lead acid (SLA)
Battery Charger:	115V AC SLA “smart” charger, 1.5A current, connected via external cable to front panel connector
Fuses:	One 20A ATO-style fuse, one 1A, 5mm bullet-type fuse
External Power:	11.5 to 13.5 V DC, 10A max current with main battery installed, 20A max current without main battery installed, connected via external cable with cigarette lighter adapter to front panel connector
Audio amplifier:	400W, 4Ω class D amplifier, 83% efficiency
Stepup transformer:	Edcor custom transformer
PDA Power:	Supplied via internal 12V auto adapter using DC-DC converter
Operation time:	At least 2 hours using 25% duty cycle (actual over 4 hours with fully charged battery)
Recharge Time:	Depends on battery drain:

Hours of use at 25% duty cycle	Approx. Recharge Hours
1	1.75
2	3.5
3	5.25
4	7

7.2 Mechanical

Control Unit:	Weight 35 lb Size 18.25” by 14” by 6.75” Manual vent (normally closed) Case color: Gray with adhesive labels
Transducer Case:	Weight 25 lb Size 19.5” by 15” by 7” Manual vent (normally closed) Case color: Gray with adhesive labels
Transducer Array:	Three elements, 24” center-to-center spacing, wired in parallel Cable length: 75 ft (Suprene 105, 18 ga) Array to be deployed vertically, maximum recommended 15^{o} tilt angle (note ballast weight not included) Support line: ¼” double braided nylon, maximum load 100 lb

7.3 Computer / Software

PDA Computer:	Hewlett Packard hx2400 series or similar running Windows Mobile 5.0 operating system. PDA must have at least one Secure Digital™

	(SD) slot. PDA must have non-volatile (flash) memory and be capable of operating without the PDA battery installed.
SD Card:	256 MB or larger Secure Digital™ Card
*e*LOUD™ Control Software:	Custom software, current version is 1.2
Sound File Format:	Microsoft Wave format, 11,025 Hz sample rate, 16 bit mono, maximum nondimensional level of 0.95 (integer of 31130).

7.4 Environmental

Control Unit:	Operating temperature -10^{o}F to 100^{o}F, Charging temperature 4^{o}F to 100^{o}F Humidity 100% with case vent closed Submersion depth 3 ft with case vent closed and lid closed
Transducer Array:	Operating temperature -10^{o}F to 100^{o}F Maximum depth 130 ft (although limited to 75ft by cable length)

7.5 Component List

Version 1.2

Item	Manufacturer	Part Number	Quantity
Battery, 12 Ah, 12 VDC, SLA	Batterymart	SLA-12V12	1
Battery Charger	Cliplight	ACC-OEM-61201-5	1
Amplifier with installation kit	Harrison Labs	AMP-400-4	1
Transformer	Edcor	Custom	1
PDA, HP hx2490	HP	FA675A	1
PDA Auto charger	HP	F8Q2000QHP	1
Secure Digital Card, 256 MB	Sandisk	503991	1
Microphone	Shure	527B	1
Potentiometer for microphone, 5kohm	Digikey	3310C-001-502-ND	1
Knob for microphone potentiometer	Digikey	8554K-ND	1
PDA flex screen	Otter Products	2600-A3	1
Power switch	GC	GC-35-080	2
Power switch boots	GC	GC-35-060	2
Power lockout cover	Action Electronics	PH-30-1250	1
Enclosure with bezel kit uninstalled, gray, manual purge	Hardigg	iM2300	1
Enclosure for transducers, pick and pluck foam, manual purge valve	Hardigg	iM2400	1
Transducer array	Ocean Engineering	DRS8-3 array	1
Microphone connector (plug)	Amphenol	PT06E8-4P(SR)-ND	3
Microphone connector (recepticle)	Amphenol	PT02E-8-4S-ND	3
Transducer connector (plug)	Amphenol	PT06E12-3P(SR)-ND	3
Transducer connector (recepticle)	Amphenol	PT02A12-3S-ND	3
External power connector, male pins (plug)	Amphenol	97-3106A-18-10P-ND	4
External power connector, female (recepticle)	Amphenol	97-3102A-18-10S-ND	3
Cable clamp with bushing for power plugs	Amphenol	97-3057-1010-1-ND	4
Battery Voltage meter	Martel Electronics	QM-100V	1
Front panel (engraved)	Custom	Custom	1
BNC Jack, Isolated	Action Electronics	PP-BNC3199	2
RCA plug for amplifier	Action Electronics	VN-PP5	1
Audio plug, right angle, 4 conductor	Action Electronics	CR-30-702	1
BNC to RCA adapter	Triangle Cables	200-173	1
RCA to stereo 1/8" adapter	Radio Shack	274-387	1
Monitor speakers	Radio Shack	40-1441	1
Fuse holder (for power amp), 30A, 10 gauge	Radio Shack	270-1234	1
Fuse Holder	Radio Shack	270-1238	1
Fuse, 500 mA, pack of 4	Radio Shack	270-1061	1
Protective cap, amphenol 9760-18	Amphenol	714-2546	1
Cig lighter plug	Allied Electronics	283-1175	1
Cig lighter socket	Allied Electronics	283-1201	1
Power bus	Blue Seas	196976724	1
Velcro cable ties for transducer cable, 5-pack	Ancor	199326273	1
Protective cap, Amphenol 10-101960-083	Allied Electronics	233-0930	1
Protective cap, Amphenol 10-101960-123	Allied Electronics	233-0127	1
Fuse, 20 A, ATO Blade syle	Radio Shack	270-1083	3
Nylon Rope, 80 ft, 1/4" double braided	McMaster-Carr	3836T92	1
Ring, stainless steel, for rope, pack of 10	McMaster-Carr	90905A656	2
Battery clips for cigarette lighter	Tower Electronics		1
Spare parts and folder labels	Custom	n/a	2
TSWG Labels	Custom	n/a	2
Box Labels (Control Unit and Transducers)	Custom	n/a	2

8. *e*LOUD™ Quick-Reference Card

The quick-reference card on the following two pages is included as a laminated card in the *e*LOUD™ control unit case. It is intended to help users quickly set up and operate the *e*LOUD™ system but is not intended to replace the User's Manual.

Applied Physical Sciences Corp.

*e*LOUD™ Enhanced Underwater Loudhailer (Version 1.2)
Pre-recorded Phrase List

"m" denotes male speaker, "f" denotes female
All phrases are preceded by a siren tone

Examples:
English1m.wav: English phrase 1, male speaker
English15f.wav: English phrase 15, female speaker

Phrase List:

1. Attention diver. This is the United States Coast Guard. You have entered a restricted area. Surface immediately.
2. Attention diver. This is your final warning. Surface now or we will use deadly force.
3. Stop now. You have entered a restricted area.
4. Attention Diver. Surface immediately.
5. This is the United States Coast Guard.
6. Surface or we will use deadly force.
7. This is your final warning.
8. Surface with your hands in the air
9. This is a restricted zone.
10. You must surface now.
11. This is the United States Navy.
12. This is a controlled area.
13. Warning. You have entered a restricted area.
14. This is your second warning.
15. Attention Diver. You must surface now.
16. Surface immediately. Surface immediately.
17. Stop. You will be harmed.
18. You are required to surface now.
19. Attention Diver. You must stop.
20. Come up to the surface now.
21. This is your first warning.
22. Come to the surface now.
23. This is a notice to all divers.
24. Attention swimmer. You must stop now.
25. This is a restricted area.

Available Sirens/Tones:

Siren3: Hi/Low siren (Recommended)
Siren4: Faster Hi/Low siren
tone550: 550 Hz tone, 4 seconds long
tone2_7k: 2700 Hz tone, 4 seconds long

Applied Physical Sciences Corp.

*e*LOUD™ Enhanced Underwater Loudhailer (Version 1.2)
QUICK START INSTRUCTIONS FOR PLAYING DEFAULT MESSAGE LIST

WARNINGS:

- DO NOT OPERATE SYSTEM WHEN DIVERS ARE WITHIN 50 YARDS OF TRANSDUCERS
- DO NOT OPERATE SYSTEM WITH DAMAGED TRANSDUCER CABLE OR CONNECTORS
- DO NOT OPERATE SYSTEM IN SWIMMING POOLS OR ENCLOSED SPACES

1. Detach Control Unit charger and close case. Transport Control Unit and Transducer Case to OPAREA.
2. Open Transducer Case, remove transducer array, and uncoil yellow cable.
3. Attach weight to rope at bottom end of array if there is an ocean current (50 lb or less)
4. Lower array into water letting the rope support the weight. Lower to at least 10 ft depth or preferably to half total depth (50 ft max). Secure rope to cleat.
5. Open Control Unit and attach transducer cable connector to Control Unit Front Panel ***Transducer*** connector.
6. Turn main power on. The *e*LOUD software program will load in approximately 25 seconds. A default playlist should be shown. If not, refer to instruction manual to set up a playlist.
7. Click the volume control on the PDA (small speaker in top right corner) and set to maximum volume
8. Turn the ***Transmit Enable*** switch on.
9. Press the **PLAY** button on the PDA. The messages will load and you should hear sound from the transducer array.
10. When finished turn off the Transmit Enable and Main Power switches and refer to the manual for cleaning and storage procedures.